Reports

Alaskan Earthquake of 27 March 1964: Remote Seiche Stimulation

Abstract. *After the intense Alaskan earthquake of 27 March 1964, unusual waves up to 6 feet (about 2 meters) in height occurred at about the time of arrival of seismic waves at many localities along the coasts of Louisiana and Texas. The parameters of local channels at the tide gauge in Freeport, Texas (the only instrument to record significant waves) yield seiche periods close to those of the seismic surface waves suggesting that the water waves were generated by and in resonance with the seismic waves.*

According to the preliminary report of the U.S. Coast and Geodetic Survey (*1*) the Alaskan earthquake of 27 March 1964 caused direct tsunami waves in the Pacific Ocean which reached heights up to 30 feet (9 m) at the coast. In several reports from eyewitnesses in the coastal regions of Louisiana and Texas, waves up to 6 feet (2 m) in height were described. Many swimming pools were reported as overflowing in the southern parts of both states. The strongest waves recorded were those registered on the tide gauge at Freeport, Texas. Because these waves arrived at the time of the seismic waves and are geographically disconnected from any possible tsunami, they appear to be of local origin, probably seiches generated in resonance with the seismic waves.

Oscillations with a short period were recorded by the Freeport tide gauge shortly after the arrival of the first compressional (P), shear (S), and surface waves (Love and Rayleigh waves). The actual period cannot be determined from the marigram shown in Fig. 1 because of the compressed time scale. The maximum height of the recorded seiche at 0400 GMT is about 7 inches (18 cm) according to the vertical scale in Fig. 1. Since the tide-gauge flat that senses the water level rises and falls in a well open to the water only through small perforations, a considerable attenuation of short-period waves occurs. Response curves of such tide-gauge wells are not available and probably would not be too reliable because of marine growth, but the true wave height may have been several feet (about a meter). The location of the Freeport tide gauge and the adjacent interconnecting waterways are shown in Fig. 2. The disturbances in other restricted bodies of water were probably caused by the same effect.

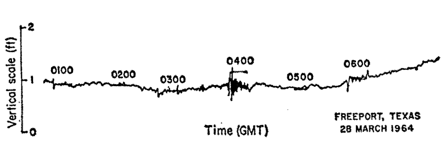

Fig. 1. Marigram from Freeport, Texas, showing the seiche beginning just prior to 0400 (*1*).

The time scale of the marigram does not permit a precise determination of the time at which the waves occurred, but the prominent group of waves which begins to build up shortly before 0400 GMT corresponds to the arrival time of the strong surface waves in this region. The first mode Rayleigh waves at Houston, Texas (one degree north of Freeport) were reported by De Bremaecker (*2*) to have a period of 16 seconds and a double amplitude of about 16 inches (15 cm). The amplitude was determined from the air pressure effects of the vertical piston action of the Rayleigh waves since these waves were well off scale on the seismograms. The preceding Love waves of somewhat longer period were soon submerged in the train of strong Rayleigh waves.

By using the seiche formula for a closed basin, $T = 2L/\sqrt{gh}$, where T is the period, L is the width of the basin, g the acceleration of gravity, and h the depth of water, a number of period determinations were computed for several profiles (*A* through *E* in Fig. 2) across the waterways in the vicinity of the tide gauge. The results were: *A*, 20 seconds; *B*, 24 seconds; *C*, 47 seconds; *D*, 12 seconds; *E*, 36 seconds.

All of these results, which are close to the periods of Love and Rayleigh waves, might be in error by up to a few seconds since there is some uncertainty about the true depths along the profiles. Although the Rayleigh wave period (16 seconds) of profile *C* corresponds almost exactly with the second harmonic of the computed seiche period, it is difficult to separate the excitation effect of the Rayleigh waves from that of the slightly longer period Love waves, especially in view of the conclusion of McGarr (*3*) that the horizontal acceleration of surface waves would be the most effective stimulant.

It seems from this analysis that resonance or near resonance between the seismic surface waves and the fundamental of the seiches, some low harmonic of the seiche, occurred in the waterways near or at the tide gauge as the result of the shaking motion of the ground. This explanation of the Freeport water disturbance is probably applicable to other disturbances reported in the coastal region of the Gulf of Mexico and perhaps to disturbances in other localities as well.

Another factor that may have been partly responsible for the prominence of the seiches in Louisiana and Texas was the great height of the seismic surface waves in this region. As reported by De Bremaecker, they were significantly higher than seismic waves recorded at many stations having comparable or closer distances to the earthquake epicenter. The thick column of sediments composing the coastal plain of the Gulf of Mexico may respond to the seismic waves with greater ground motion than regions of crystalline rock or thin sediments. This was suggested by Donn (*4*) as the explanation of anomalously high microseisms

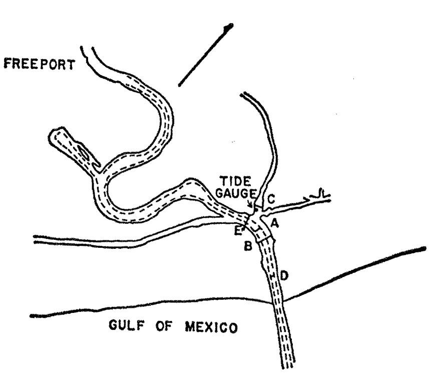

Fig. 2. Location of tide gauge and coastal channels near Freeport, Texas (28°57′N, 95°19′W). (From Coast and Geodetic Chart No. 887)

recorded along the Gulf Coast from cyclonic storms off the Coast of Labrador.

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References and Notes

1. Seismology Division, U.S. Department of Commerce, Coast and Geodetic Survey, *Preliminary Rept. Prince William Sound, Alaskan Earthquakes March–April 1964* (Washington, D.C., 1964).
2. J. C. De Bremaecker, reported at the annual meeting of the American Geophysical Union, Washington, D.C., 1964.
3. A. McGarr, in preparation.
4. W. Donn, *Trans. Am. Geophys. Union* **38**, 354 (1957).
5. This investigation, which was supported by grant NSF-GP-550, is Lamont Geological Observatory (Columbia University) contribution No. 726.

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Biological Remnants in a Precambrian Sediment

Abstract. *A billion-year-old shale from the Nonesuch formation at White Pine Mine, Michigan, contains microfossils, porphyrins, and optically active alkanes. Pristane and phytane, which are isoprenoid hydrocarbons found in living plants and animals, are constituents of the ancient alkanes in the Nonesuch shale; the presence of porphyrins in this Precambrian sediment suggests that photosynthetic organisms have existed for more than a billion years.*

Most information about the inhabitants, climates, and physical features of prehistoric continents and oceans has been deduced from biological remnants found in sediments. Extensive data have been gathered on the fossils and organic materials of Cambrian to Quaternary age (*1–4*), but publications discussing Precambrian remnants of life are limited in number (*5*).

We are analyzing microfossils and carbon compounds from the Nonesuch shale of upper Precambrian age (Keweenawan, 1.1×10^9 years). This shale is a major sedimentary unit of the late Precambrian sequence of northern Michigan. The dense gray to black shales in the lower part of the formation are copper bearing and are currently being exploited in an extensive mining operation. The shales contain sporadically distributed vugs filled with small amounts of liquid hydrocarbons occurring as crude oil. Petroleum also occurs in fractures in these lower shales.

Micropaleontological study of the acid-insoluble organic fractions of the shale has revealed the presence of abundant, finely divided plant tissue, largely of unorganized morphology, except for occasional filaments and spherical spore-like bodies. The organic and petroliferous content of the shale, and its correspondingly darker color, are positively correlated with the relative abundance of the discrete organic fragments. The presence of fossil microorganisms in the Nonesuch shale lends credence to the interpretation that the petroleum and associated biogenic compounds are indigenous to the shale and represent original organic matter syngenetic with deposition.

Alkanes from the benzene extracts and crude oils of the Nonesuch shale were isolated by silica gel chromatography (*6*). The alkane fractions represent 60 percent (by weight) of the extract and oil samples. Optical activities of these alkanes are (*7*): $[\alpha]^{35°}_{5460} = 0.541$ deg and $[\alpha]^{35°}_{5780} = 1.569$ deg. Liquid-solid and gas-liquid chromatographic, mass spectrometric, and infrared and ultraviolet spectroscopic analyses have been obtained on the saturated and aromatic hydrocarbon fractions of the Nonesuch extracts and crude oil. The extracts and oil resemble certain paraffinic crudes of Paleozoic ages, but the optical activities of alkanes from this Precambrian shale exceed those reported for some Pennsylvanian and Midcontinent oils (*8*).

Pristane (2,6,10,14-tetramethylpentadecane) and phytane (2,6,10,14-tetramethylhexadecane) have been identified (*9*) in the Nonesuch alkanes. These isoprenoid-type hydrocarbons are commonly found in biological and sedimental lipids (*10*). Identifications of pristane and phytane in the Nonesuch samples were accomplished by gas-liquid chromatography on a series of four capillary columns (0.25 mm $\times$ 30 m) which were individually coated with one of four different liquid-solid chromatographic fractions of Apiezon L (*11*). These identifications were confirmed by liquid-solid chromatography on alumina columns and mass spectrometric analyses by previously described methods (*12*). Concentrations of pristane and phytane in Nonesuch alkane fractions approximate 0.5 and 0.3 percent, respectively. Gas-liquid chromatography analyses of these alkanes reveal a slightly greater abundance of odd- than of even-number carbons in *n*-paraffins in the C_{23} to C_{31} range. *n*-Paraffins from living things frequently show a strong "odd carbon preference" in this carbon number range (*3*). The "odd carbon preference" observed in the Nonesuch alkanes is as great as that found in most crude oils and ancient sedimental extracts (*13*), irrespective of the ages of the sediments. The concentrations of pristane and phytane in the Nonesuch oil and the retentions of optical activity and the "odd carbon preference" by the Nonesuch alkanes indicate a remarkable stability of certain plant and animal products in sedimentary environments (*11*). Analyses of the hydrocarbons from the Nonesuch extracts and crude oils reveal that these apparently one-billion-year-old alkanes retain an accurate record of their biological origin just as the hydrocarbons in many geologically young oils do. The capacity of certain organic materials to retain their identities for more than a billion years in some sediments is demonstrated also, by porphyrins from the Nonesuch shales.

Treibs (*4, 14*) first demonstrated the presence of porphyrins in bituminous strata and he presented them as evidence that these strata had experienced a mild thermal history. Calculations based on the activation energy for the degradation of porphyrins have been used to prepare a time-temperature curve from which the maximum temperature of a porphyrin-containing deposit of known age can be estimated (*15*). Extensive investigations have been made of the occurrence of porphyrins in petroleum and sediments and of the relation between them and chlorophyll and hemin (*2, 4, 14, 16*).

Porphyrins isolated from the Nonesuch shale have well-defined peaks at 534 and 573 mμ and they exhibit the typical Soret absorption band near 400 mμ. Polarities of the Nonesuch porphyrins, as demonstrated by their absorption properties on alumina chromatographic column (*17*), and the visual absorption peaks of these compounds establish them as vanadyl porphyrins. The Nonesuch shale appears to be the oldest formation in which the presence of porphyrins has been found. Their presence in these deposits constitutes evidence of the existence of photosynthetic organisms in Precambrian times and that the temperatures for the Nonesuch sediments has never been very high.

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