1 and 2) (the gut refers to all tissues other than the mantle, gill, and adductor muscle). The hepatopancreas may be the site of hydrocarbon storage in mussels; recent investigations have shown that hydrocarbons are stored in the gallbladder and liver of marine fish (*10*).

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18.6-Year Earth Tide Regulates Geyser Activity

Abstract. *Over 40 years of records from Yellowstone National Park, Wyoming, show that the 18.6-year tidal component strongly regulates the frequencies of eruption of Grand and Steamboat geysers. The frequency of Grand Geyser increases with increasing tidal force and that of Steamboat Geyser decreases, which suggests that tidal dilatation is one factor affecting heat flow to a geyser.*

It has been established that earth tidal forces have a regulatory influence on geothermal activity (*1*). The interval between eruptions of Riverside Geyster in Yellowstone National Park was found to be especially responsive to the fortnightly and semiannual components of the tidal forces. It was also found that, over a 6-year period in which careful records were kept, the interval between eruptions of Old Faithful Geyser in California decreased essentially linearly with increasing tidal force. The variations in geyser activity are attributed to mechanical straining by the tidal forces of the geothermal area in which the geyser is located. Such strains could be expected to influence the rate of heat flow to the geyser. Further examination of the Yellowstone records shows that at least two geysers, Grand and Steamboat, respond dramatically to the 18.6-year tidal component. This appears to be the first time that the influence of the 18.6-year component has been observed in a solid earth geophysical phenomenon.

The earth tidal forces, arising from the gravitational attraction between the earth, the moon, and the sun, cause the ebb and flow of the ocean tides and, in addition, deform the solid part of the earth, producing strains of the order of 10^{-7} which vary in synchronization with variations in the tidal forces. The maximum variation in gravity due to lunar and solar attraction is about 1 part in 5×10^6 times the acceleration of gravity. Since the earth rotates on its own axis, the moon revolves around the earth, and the earth around the sun, the tidal force is constantly changing, and its magnitude at any one place on the earth depends on the relative positions of the earth, moon, and sun. In general, the variations are periodic, having the following approximate frequency components: semidiurnal, diurnal, fortnightly, semiannual, 8.8-year, 18.6-year, and 20,900-year. The overall tidal force, although it is made up of numerous periodic components, does not itself display a periodically regular pattern. The values of the variation in gravity due to tidal forces are readily calculable by using Longman's method (*2*).

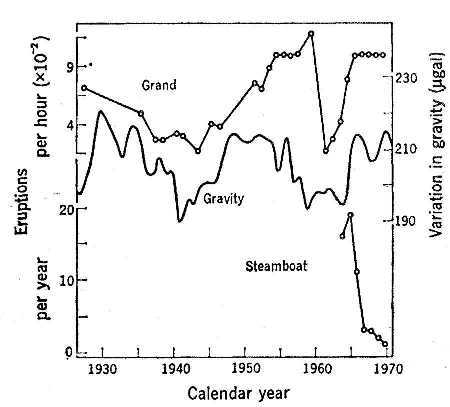

Fig. 1. Observed temporal variations in frequency of eruptions of Grand and Steamboat geysers and computed average annual spread between maximum and minimum gravity due to earth tidal forces.

The 18.6-year component arises from the inclination of the orbital planes of the earth and the moon, about 5° with respect to one another. The inclination causes the average tidal force to vary about 10 percent during an 18.6-year period.

Many records have been kept by the park naturalists on geyser activity in Yellowstone National Park. These records, usually in the form of periodic informal reports and personal notebooks, while often fragmentary, can be pieced together to give fairly reliable histories of the activities of some of the geysers. The activities of two of the major geysers, Grand and Steamboat, are especially noteworthy when compared with moderately long-term changes in earth tidal forces.

Grand Geyser is situated in the Upper Geyser Basin. During an eruption it will play to a height of 30 to 60 m, for anywhere from 15 minutes to 1½ hours. According to Marler (*3*), the interval between its eruptions varies from 8 hours some seasons to over 40 hours other seasons, with two periods of dormancy over the four decades of observations. Steamboat Geyser lies in the Norris Basin, some 30 km from Grand Geyser. It is the most stupendous geyser in the park, erupting to a height of 100 to 130 m and playing several hours. The characters of the two basins are quite different (*4*). Upper Geyser Basin is the older of the two, containing many perfect geysers such as Old Faithful, Grand, and Giantess. The younger Norris Basin exhibits a much wider range of phenomena, from very new geysers to well-established ones.

The historical records of the activities of Grand and Steamboat geysers are presented in Fig. 1, where average frequency of eruption has been plotted as a function of year. The data for Grand cover the relatively long period from 1927 through 1969; those for Steamboat are less extensive, being available only for the 6-year period from 1963 through 1969. The annual average earth tidal force is also plotted in the same figure. The ordinate in this case is the computed total average annual spread between maximum and minimum gravity rather than the average of either.

There are strong correlations between frequency of eruption and variation in earth tidal force. During times of high tidal force, around 1930, 1955, and 1970, Grand Geyser erupted two to three times daily, only to become almost dormant during the years 1943 and 1960, when the tidal force was lowest. Grand's behavior is similar to although more striking than that observed in Old Faithful of California (*1*). On the other hand, the major activity of Steamboat is just the opposite, the tremendous eruptions occurring during periods of low tidal force. The correlation coefficient between frequency of eruption and variation in tidal force is 0.5 for Grand and -0.4 for Steamboat. However, a 1-year phase shift increases the correlation of Steamboat to -0.9, which suggests that there may be a short time delay in the response of the geyser to the tidal force. A similar shift in the case of Grand causes a slight decrease in correlation.

Geyser activity is controlled largely by the rate of heat flow to the geyser reservoir, the heat input being in the form of intermittent injections of superheated water flowing through the porous fractured mass of the geothermal area in which the geyser is located (*5*), so that it is not surprising that forced compression and expansion of the mass would influence the rate of flow. It is somewhat unexpected that an increase in the tidal force may in one instance increase and in the other instance decrease the rate of flow. However, Grand and Steamboat lie in distinctly different types of geothermal areas, which could well react differently. In this connection, it is probably noteworthy that Norris Basin began acting up during the summer and fall of 1971 (*6*), a time of relatively high tidal force. The pools and mud pots became exceedingly active while geyser activity lessened, which suggests that the high tidal forces changed the pattern of circulation, sapping energy from the geysers to feed the pools. No such shift was observed in the Upper Geyser Basin.

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Air Pollution: Sensitive Detection of Ten Pollutant Gases by Carbon Monoxide and Carbon Dioxide Lasers

Abstract. *Detection sensitivities of a few parts per billion for ten gaseous pollutants have been evaluated by measuring the strength of the absorption of infrared radiation from carbon monoxide and carbon dioxide lasers. Ethylene concentrations as small as 5 parts per billion have been detected in air. The measured absorption strengths indicate that in mixtures of pollutants, such as nitrogen dioxide and water vapor, the sensitivity is reduced by overlapping absorption bands. However, calculations indicate that it should be possible to detect nitrogen dioxide concentrations of 0.01 part per million in the presence of water vapor concentrations of 10^5 parts per million.*

The absorption of infrared radiation at various emission wavelengths of the CO and CO_2 molecular gas lasers has been measured for ten different gaseous pollutants. It was found to be large enough to allow detection of pollutants in concentrations as small as a few parts per billion, and specific enough to allow identification of a gas in the presence of (10^4 times) larger concentrations of other absorbing gases. The ten gases were selected because of their importance in air pollution studies. They include some of the more photochemically reactive hydrocarbons in automobile exhaust and also NO and NO_2. These gases are important contributors to photochemical smog. In this report we show that the detection technique for gaseous pollutants is simplified if molecular gas lasers (*1*) are used together with the optoacoustic detection scheme (*2*) rather than the more complex spin flip Raman laser (*3*). Also, we find that the detection sensitivity is greater by more than one order of magnitude over previous reports.

The experimental apparatus is represented in Fig. 1A. Infrared absorption in the gas sample is measured by means of the optoacoustic effect (*2*). An amplitude-modulated beam of infrared radiation is directed through the gas sample, which is enclosed in a container. The energy absorbed by the gas causes its temperature and pressure to rise. This pressure rise, which is periodic because of the amplitude modulation of the infrared beam, is detected by a microphone placed inside the sample container. The electrical signal from the microphone is proportional to the infrared beam power and the gas absorption strength. Absorption strengths as small as 4×10^{-9} cm^{-1} per watt of beam power have been detected. In order to detect small absorptions due to low concentrations of air pollutants, high beam power is required. Specificity, the ability to prevent other gases from interfering with the measurement, requires that the spectral width of the radiation be narrow. In conventional infrared spectroscopy, blackbody sources and grating or prism monochromators have been used to provide beams of narrow spectral width. These sources cannot provide sufficient power over a narrow enough spectral range to give adequate sensitivity and specificity. They have been useful for detecting gases in high concentrations when no other sample constituent absorbs in the wavelength range of interest. Hydrocarbons and CO in automobile exhaust can be detected by this means, but the nitrogen oxides cannot because of interfering absorption by water vapor, which is a normal constituent of automobile exhaust and ambient air.

These difficulties can be largely overcome by using a laser infrared source. Nitric oxide has been detected (*3*) by using a spin flip Raman laser, which has continuous wavelength tuning. Molecular gas lasers are not continuously tunable but can be made to emit in a number of discrete wavelengths corresponding to transitions between various inverted energy levels in the laser gas. An emitted wavelength is selected by rotating a diffraction grating, which forms one end of the laser optical reson-