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Infrared Rainbow

Abstract. *Radiation in the near-infrared spectral region should produce a rainbow that is not visible to the human eye. An infrared photograph is shown which displays the primary bow, the secondary bow, and two supernumerary bows inside the primary bow.*

The rainbow has long been a cause for wonder and delight to observers. The explanations of its origin and of a variety of its subtle features have paralleled the development of the principles of geometrical and physical optics. To a person who takes pleasure in contemplating the rainbow, the question "Does there exist an infrared rainbow?" would seem to be one of natural interest. I have been unable to find the question raised in any published literature and, although the subject may not be profound, it raises an interesting speculation.

For the infrared rainbow to exist, the radiation from the sun, after having traveled through a long atmospheric path, must still have an infrared component. Measurements show (*1*) that, even for long slant paths through the atmosphere, there is appreciable energy in the near-infrared region out to wavelengths of at least 2.5 μm (2500 nm). Another requirement is that raindrops must be transparent to the radiation forming the bow. For path lengths as great as a centimeter, water transmits appreciably for wavelengths out to about 1.3 μm (*2*).

The conclusion from these considerations is that there should indeed exist a rainbow of near-infrared radiation. To record this bow, I used Eastman Kodak infrared film IR 135, in conjunction with a Kodak 87C filter. This combination of film and filter made it possible to isolate a band pass, centered at 865 nm, which is separated from the visible part of the spectrum. Figure 1 shows the film sensitivity and filter transmittance along with the spectral sensitivity of the human eye, which serves to define the visible region of the spectrum.

The infrared photograph (Fig. 2) shows that the primary infrared rainbow (resulting from one internal reflection in the raindrops) is quite bright. Outside this primary arc, the secondary rainbow (resulting from the two internal reflections) is visible. Just inside the primary bow are two supernumerary bows which can be explained as an interference phenomenon arising from rays which emerge from the raindrop at the same angle but which have taken different paths through the drop [see Humphreys (*3*) for a more complete discussion of this effect].

These effects are, of course, known and understood from their occurrence in visible light (and one could predict their occurrence in the near-ultraviolet spectral region). There is, however, a

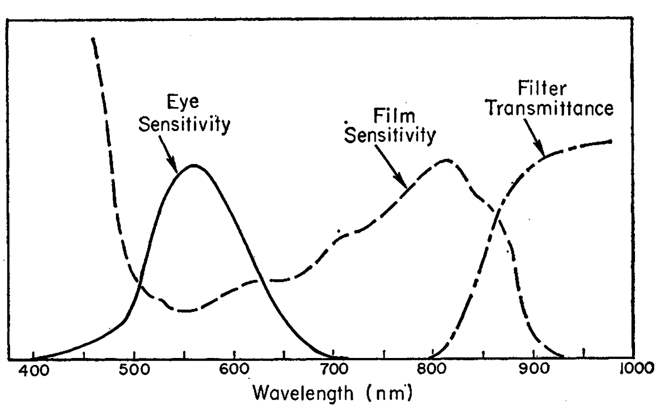

Fig. 1 (left). Relative spectral sensitivity of the human eye (——) [data for foveal cones taken from Wald (*4*)]. Relative spectral sensitivity of Eastman Kodak infrared film IR 135 (– – –) (data from Eastman Kodak Co.). Transmittance of the Eastman Kodak 87C infrared transmitting filter (- — -) (data from Eastman Kodak Co.). Fig. 2 (right). Photograph of the infrared rainbow.

fascination in "seeing" for the first time an infrared rainbow which has hung in the sky undetected since before the presence of man on this planet.

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3 May 1971

Explosion Effects and Earthquakes in the Amchitka Island Region

Abstract. *Microearthquakes were monitored by a network of seismographs located on Amchitka and nearby islands; the nature of earthquake activity in this region was found to be consistent with the hypothesis of underthrusting of the Aleutian arc by a rigid lithospheric plate. Seismic effects of the nuclear explosion Milrow were small, of short duration, confined to the region immediate to the explosion, and were apparently independent of this geotectonic mechanism.*

An important consequence of the hypothesis of sea-floor spreading is that the earth's major tectonic features are the result of the relative movement and interaction of rigid lithospheric plates over its surface (*1*). Plate boundaries are marked by relative motion along transform faults and by zones of convergence or divergence of lithospheric material. Because the locus of most of the world's seismic activity also lies along these boundaries it is little wonder that the concept of plate tectonics receives its widest support from the observations of seismology (*2*). Island arcs, like the Aleutians, are typically zones of convergence, that is, they are underthrust by oceanic plates. Hence, the nature of earthquake activity in the Amchitka Island region is deeply rooted in the tectonics of the entire Aleutian arc and to global movements in general. In view of present interest in the effects of nuclear testing on Amchitka Island, it is imperative that we report important new seismological data relevant to understanding the tectonics of the region and observable seismic effects from the nuclear explosion Milrow (October 1969, about 1 megaton) have been obtained.

In 1969, at the request of the Atomic Energy Commission (AEC), the National Ocean Survey undertook an Aleutian seismic program which included the interpretation and reduction of data from a network of seismographs that continuously monitored activity in the Aleutian Islands and Alaska. This seismic network had three purposes: (i) to monitor the seismicity of the entire Aleutian arc; (ii) to monitor extremely low-level seismic activity in the Amchitka Island region to describe accurately the natural patterns which would be observable on a larger scale over a longer period of time; and (iii) to document the effects from underground nuclear explosions on Amchitka Island.

A regional seismic network was established by supplementing seismographs, already operating in Alaska and on Adak Island as part of the Alaska regional tsunami warning system, with new installations at Granite Mountain in northwest Alaska, and at Shemya and Nikolski in the western and eastern Aleutians, respectively (*3*). To monitor low-level seismic activity in the Amchitka Island region, seismographs with high-gain and high-frequency response characteristics were installed on Amchitka and nearby islands (*4*).

Epicenters for selected seismic events detected by the Amchitka network during 1969 and 1970, together with larger events located independently using teleseismic data, are plotted in Fig. 1. Epicenters at focal depths of 0 to 50 km demonstrate a strong correlation with structural features expressed in the bathymetry of the sea floor; this suggests that these features are the direct result of oblique underthrusting by the oceanic plate. Deeper earthquakes appear more evenly distributed along a steep dip that extends northward from the ridge crest to depths in excess of 200 km, just beyond the volcanic arc. Epicenters of the very deepest events lie primarily in a northeast-trending zone coincident to the intersection (and possible superposition) of the Aleutian arc with the Bowers Ridge, a large arcuate aseismic structure extending into the Bering Sea. This distribution in focal depth becomes more evident by projecting hypocenters within the Rat block into the section A–A′, illustrated in Fig. 2. The geometry of the seismic activity is similar to that obtained in other zones of convergence (*2*) and supports the model of an underthrusting lithospheric plate. The seismicity demarcates the plate, confirms the extent of the seismic zone to within 50 km or less, and lends convincing support to the hypothesis that, below the zone of underthrusting, earthquake-generating stresses are contained within lithospheric material that has descended into the mantle (*2, 5*). These are all significant evidence for the plate tectonics concept. Local flexures, volcanism, and possible lateral movements in the overthrusting lithospheric plate give rise to scattered shallow-focus activity above the inclined seismic zone.

Further evidence that island arcs are zones of convergence comes from focal mechanism studies (*5, 6*). In Fig. 1, continued underthrusting of the Aleutian arc is indicated by long-period body-wave focal mechanism solutions for four large events in 1969. These solutions are not only consistent with earlier patterns (*6*), but also mark the western margin of the Delarof block as a region of current large-scale tectonic activity.

Major Aleutian earthquakes often precipitate aftershocks that, in some instances, continue for a year or more over zones which include large portions of the arc (*7*). The generally sharp boundaries of these zones suggest that isolated segments of the Aleutian arc are activated independently. Aftershock sequences of major earthquakes occurring in 1957 and 1965 are evidence for the existence of such a boundary between the Rat Islands and the Delarof Islands, approximated by the dashed line in Fig. 1 (the western margin of the Rat block and eastern margin of the Delarof block are near 177°E and 177°W, respectively, along deep canyons which indent the ridge). This view is further supported by structural features inferred from the bathymetry and by an apparent offset in the volcanic arc.

More recent data also suggest a significant difference in the distribution and amount of seismic activity between the blocks. This is demonstrated in the upper portion of Fig. 3 by the cumulative daily strain release, which was computed independently for each block using only events detected at teleseismic distances to insure uniformity. Although the blocks are approximately the same dimensions, strain release in