sweep from 3.1 to 3.6 kHz, or a control (blank) tape. Behavior, movement, and underwater vocalizations were monitored and compared with baseline periods. While the two types of sonar signals differed in their effects on the whales, both elicited avoidance behaviors. Humpbacks responded to the pulse by increasing their distance from the sound source. The strength of this effect varied directly with time. Responses to the frequency sweep primarily consisted of increased swimming speeds and track linearity. The latter was a direct function of increasing sound intensity. Overall, the sounds did not strongly or consistently affect the whales' dive cycles or vocalizations. Observed avoidance reactions may have resulted from possible resemblance between the sonar signals and natural sounds in humpbacks' environment that are associated with biological threats or warnings.

2:00

4pAB5. Vocalizations of blue and fin whales during a midocean ridge airgun experiment. Mark A. McDonald, John A. Hildebrand, Spahr Webb, LeRoy Dorman (Scripps Inst. of Oceanogr., Univ. of California, La Jolla, CA 92093-0205), and Christopher G. Fox (OSU Hatfield Marine Sci. Ctr., Newport, OR 97365-5258)

Numerous seismic experiments are conducted each year in the deep oceans to study the nature of oceanic crust and to map the source of seismic signals associated with small earthquakes or volcanic activity. Whale vocalizations of the type associated with blue and fin whales are often recorded on the arrays of seafloor seismometers and hydrophones used for these experiments. These whale vocalizations are characterized from one such experiment conducted about 500-km offshore from Astoria, Oregon in August of 1990. The travel time differences and signal amplitudes from both direct and multipath arrivals across the seafloor seismometer array are used to locate the whales and predict the level of ship and airgun noise at the whale. Whale vocalizations were recorded during airgun operations and these vocalization patterns are compared to patterns recorded during times of relative quiet from the 12 days of data gathered in this experiment. Transient oceanic sound levels from transform fault earthquakes and seafloor volcanic activity are often louder than those produced by airguns.

2:15

4pAB6. Underwater earthquakes noise levels and its possible effect on marine mammals. Clyde E. Nishimura (Naval Res. Lab., Code 7420, Washington, DC 20375) and Christopher W. Clark (Cornell Univ., Ithaca, NY 14850)

Earthquakes in oceanic regions commonly generate acoustic signals known as T-phases which are similar but not identical, to man-made explosions. As earthquake-producing areas are also regions where marine mammals congregate (e.g., Aleutians and Caribbean margin), knowledge of the characteristics of T-phases may provide some additional information on the possible effect of noise on these animals. T-phases are generally characterized by acoustic energy below 100 Hz with most of its energy in the 10- to 30-Hz range. The duration of the T-phase is, to the first order, linearly related to the source earthquakes magnitude; durations of several minutes are common. The T-phase source signal level, which can exceed 200 dB *re*: 1 μPa for a magnitude 4–5 earthquake, is a complex function of the source magnitude, focal depth, and the complexity of the bathymetry at the water–rock radiation area. This radiation area is not a point source and can extend over a radius of several tens of km. As part of the Whales '93 program, analysis has begun as to whether there is any correlation between the occurrence of earthquakes and observable changes in the acoustic signature form, and the positioning of large cetaceans.

2:30

4pAB7. The reaction of humpback whales to underwater explosions: Orientation, movements, and behavior. Jon Lien, Sean Todd, Peter Stevick, Fernanda Marques (Whale Res. Group, Memorial Univ., St. John's, NF A1B 3X9, Canada), and Darlene Ketten (Harvard Med. School, Boston, MA 02114)

In 1992, local fishermen reported unusually high net collision rates by humpback whales in Bull Arm, Trinity Bay, Newfoundland (47° 45′N, 53° 50′W), an area of underwater industrial activity. As part of a study to investigate this phenomenon [see also Ketten *et al.*, this meeting], levels and types of noise—including underwater explosions—were sampled. The location and movement of a small group of humpbacks (71 individuals identified over a 19-day period) resident in Bull Arm were monitored; when possible, behavior of individuals was recorded directly. CTD profiles and bait abundance were also noted. Explosions were of high amplitude and low frequency. Measured at 1 mile from source, levels typically reached 150 dB (*re*: 1 μPa at 1 m, at 350 Hz). Following explosions, residency time and location of individual humpbacks did not change. When individuals could be observed directly, no behavioral reaction to explosions (sudden dives, abrupt movements) were seen. Although not statistically significant, more animals were sighted and resighting rates were higher in the explosion area than in other parts of the bay. However, two animals recollided with fishing gear—such reports of successive entrapments are rare.

2:45–3:00 Break

3:00

4pAB8. Blast injury in humpback whale ears: Evidence and implications. D. R. Ketten (Dept. of Otolaryngol., Harvard Med. School, MEEI, 243 Charles St., Boston, MA 02114), J. Lien, and S. Todd (Memorial Univ., St. John's, NF A1B 3X9, Canada)

To date, there is no published report of effects on marine mammal hearing from underwater explosions. External injuries consistent with inner ear damage have been found in dolphins subjected to Class C explosives, but often little change is seen in surface animal behavior near blast areas [Richardson *et al.*, OCS MMS/90-0093 (1991)]. In this study, temporal bones from two humpback whales, which died following a 5000-kg explosion in Trinity Bay, Newfoundland [Lien *et al.*, J. Acoust. Soc. Am. **94**, 1849(A) (1993)], were harvested, preserved in formalin, scanned with 1-mm-high resolution spiral CT, decalcified, and sectioned at 20 μ. Evidence of mechanical trauma was found in all four ears: Round window rupture, ossicular chain disruption, serosanguinous effusion of peribullar spaces, and dissection of the middle ear mucosa with pooled sera. In one animal, there were bilateral periotic fractures. These observations are consistent with blast injury reports in humans, particularly with damage to

victims near the source who sustained massive, precipitous increases in cerebrospinal fluid pressure. There was no evidence that the pathologies found in these whales resulted from repeated barotrauma or chronic infection, and no similar abnormalities were found in control ears from humpbacks not exposed to blasts. While the results show whales, like other mammals, are subject to severe blast trauma, it remains unclear whether lower level stimuli induce temporary and/or acute threshold shifts in marine mammals. [Work supported by ONR Grant. No. N00014-92-J-4000.]

3:15

4pAB9. Prediction of potential disturbance of baleen whales by low-frequency acoustic transients. Charles I. Malme (25 Rockwood Rd., Hingham, MA 02043)

High-energy, low-frequency sound sources are useful tools for geophysical surveying, submarine detection, and long distance acoustic tomography. These sources produce impulsive, narrow-band and swept-tonal signals at high levels in the oceanic environment. This study was made to estimate the received level-time duration characteristics of acoustic transients that can potentially influence baleen whale behavior, the species of particular concern. Findings of acoustic disturbance studies show that continuous sound levels $\geqslant 120$ dB *re*: 1 μPa produces $\geqslant 50\%$ avoidance by gray and bowhead whales. However, for impulsive airgun sounds of duration <0.5 s, effective pulse levels 30 to 50 dB higher are required to produce 50% avoidance for the same species. Little information is available on whale response to intermediate sound durations representative of some sonar and tomography source operations. Consequently, the literature on human response to acoustic transients was examined for response prediction methodologies suitable for application to whale acoustic response. Similarities were found that support the application of a modified equivalent level (L_{eq}) metric. The exposure level–time duration characteristics obtained from this analysis are preliminary estimates. The predictions should be tested using data obtained in the oceanic environment using representative sources, signals, and whales. [Work supported by the U.S. Navy.]

3:30

4pAB10. Recording, analysis, and verification of low-frequency sounds produced by Arctic offshore drilling equipment. Kenneth D. Brewer and John D. Hall (Coastal & Offshore Pacific Corp., P. O. Box 31554, Walnut Creek, CA 94598)

Digital recordings of underwater sounds produced by anchored and bottom-founded Arctic offshore drilling equipment (drilling rigs) were made during drilling and idle conditions in open water and under sea ice. Sound production was verified by recording the frequencies produced by specific pieces of equipment aboard the rigs using a single axis accelerometer. It was determined that most of the sound energy produced by both the anchored and bottom-founded drilling equipment was in the frequency band from 1 Hz to 1 kHz. The drill turntable and drive equipment on the bottom-founded drilling rig produced sounds as low as 1.8 Hz. The broadband [20 Hz to 20 kHz source level (dB *re*: 1 μPa^2@1 m] of the bottom-founded drilling rig (146.2 dB) was about 30 dB less than the broadband source level of the anchored drilling rig (178.6 dB). Acoustic transmission loss in the inshore areas of the Alaskan Beaufort Sea, where water depths are less than 100 m, was found to be slightly greater than cylindrical spreading (-11.0 to $-13.0 \log R$ dB) at the two sites about 350 km apart. [Work supported by ARCO Alaska, Inc.]

3:45

4pAB11. Variation in received level from man-made low-frequency underwater noise sources as a function of diving animal depth. William T. Ellison, Karen S. Weixel (Marine Acoust., Inc., 14 Pelham St., Newport, RI 02840), and Christopher W. Clark (Cornell Univ., Ithaca, NY 14850)

Interest in the effects of low-frequency (<1 kHz man-made noise on marine wildlife highlights the need for accurate knowledge of the spatial distribution of noise levels within a given wildlife habitat. These levels can vary significantly, particularly with respect to depth within the water column. For diving animals, the ability to measure or predict this variation with depth is a necessary factor in assessing the net impact of that noise; i.e., one needs to perform a convolution of diving patterns (depth as a function of time) with the noise pattern as a function of time and depth. Recent advances in range dependent acoustic propagation modeling allow for the ability to predict with some accuracy the transmission loss from a known source of noise as a function of source characteristics (directivity, sound spectrum, location, and depth) to any given location in a hypothetical habitat. Several examples are presented that illustrate how these models might be used to evaluate the net impact of a passing noise source on pelagic whale species. [Work supported by ONR.]

4:00

4pAB12. Modeling noise interference with animal communication. Frank T. Awbrey (Biology Dept., San Diego State Univ., San Diego, CA 92182-0057)

Regulators are proposing to set simplistic limits for anthropogenic noise in natural environments. These proposed limits specify only SPL, without regard to the method of measurement, frequency or time weighting, normal ambient levels, or spectra. In some cases such limits may be inadequate, but in others they may be much too severe, resulting in unrealistic restrictions on human activities, including scientific investigations, without real benefit to the animals. Realistic limitations on noise level should incorporate information on the time history and spectrum levels of the noise and the animals' communication signals, with estimates of hearing threshold curves. This paper outlines an initial effort to devise such a model and to estimate how seriously noise of different kinds will limit communication.

4:15

4pAB13. Sonic boom wave propagation from air into water: Implications for marine mammals. Victor W. Sparrow (Graduate Prog. in Acoust., Penn State Univ., 157 Hammond Bldg., University Park, PA 16802)