with axial thermal structure, where regions of low and high numbers of events correspond to thinner (hotter) and thicker (colder) lithosphere. Bohnenstiehl et al. (2002, 2003) and Dziak et al. (2004a) used hydrophone seismicity at the MAR to quantify the completeness level of the hydrophone earthquake catalog (magnitude ≥ 2.5) and the temporal distribution of ridge-crest aftershock sequences. Location comparisons again demonstrated significant improvements relative to more distant land-based seismic monitoring (Bohnenstiehl and Tolstoy, 2003; Pan and Dziewonski, 2005).

Dziak et al. (2004b) showed that a 2001 earthquake swarm at Lucky Strike Seamount (MAR at 37°N) was likely caused by magma intrusion. Subsequent submersible observations confirmed increased venting and microbial activity at the summit. Goslin et al. (2005) documented several large earthquake sequences along the Reykjanes Ridge south of Iceland. These sequences exhibited spatio-temporal patterns consistent with involvement of magmatic or hydrothermal processes. Escartín et al. (2008) showed that high rates of hydroacoustic seismicity at the northern MAR correlate with the locations of detachment faults that bring lower crust and upper mantle rocks to the seafloor and are typically associated with hydrothermal activity. Simao et al. (2010) showed that *T*-phase earthquakes along the MAR north and south of the Azores tend to cluster on mantle Bouguer gravity anomaly maxima. Most of these clusters seemed to be caused by magma intrusion and propagation along the ridge axis. An array of eight hydrophones is currently deployed along the equatorial MAR. The results of this monitoring effort are expected to provide new insight into volcano-tectonic processes along this poorly understood section of the ridge.

Royer et al. (2008) located more than 2,000 *T*-phase earthquakes during a 16-month deployment of autonomous hydrophones in the Indian Ocean. Southeast Indian Ridge seismicity occurs predominantly along transform faults, the Southwest Indian Ridge exhibits some periodicity in earthquake activity between adjacent ridge segments, and two large tectono-volcanic earthquake swarms were observed along the Central Indian Ridge near the triple junction.

Autonomous hydrophone arrays also have been deployed at two back-arc spreading centers, the Bransfield Strait in Antarctica (Dziak et al., 2010) and the Lau Basin in the western Pacific (Bohnenstiehl et al., 2010). The Bransfield Strait array detected 3,900 earthquakes during a two-year deployment, including eight earthquake swarms located on the 400 km long central rift zone. Only five months of the Lau Basin data have been analyzed to date; however, preliminary results indicate many of the 26,900 earthquakes detected so far are focused on the main transform (Peggy Ridge) and the large (~ 50 km) overlapping spreading center in the region.

Additional Cabled and Deployed Hydroacoustic Arrays

Sohn and Hildebrand (2001) used the Spinnaker hydrophone array (Figure 3) in the Arctic Ocean to detect tectonic earthquakes from the Gakkel Ridge and further established the effectiveness of using of *T*-phases in the Arctic for long-range earthquake detection beneath the ice canopy. Schlindwein et al. (2005) deployed seismometers on an Arctic iceflow to record the acoustic phases of volcanic explosions from the Gakkel Ridge. During 11 days, a total of 200 explosions were located at a large volcanic center, and a recent lava flow was discovered in 1999 (Edwards et al., 2001).

OHBs also have been used to study ridge-crest seismicity. Kong et al. (1992) employed seven OBHs to detect microearthquakes over a three-week period from the TAG segment of the MAR at 26°N. The high seismicity levels at 26°N have recently been interpreted as due to slip on the local detachment fault (deMartin et al., 2007). Sohn et al. (1999) recorded microseismicity using OBHs following a large eruption at Axial Volcano on the Juan de Fuca Ridge in 1998. These local earthquakes were interpreted as either slip along the caldera rim fault or shear along the volcano's southeast flank. Haxel et al. (2010) have maintained an array of four OBHs within Axial's summit caldera since 2006. The OBHs have recorded thousands of earthquakes annually, which have steadily increased through time, consistent with geodetic observations of caldera floor uplift caused by a renewed influx of magma (Nooner and Chadwick, 2009) and leading to discovery of a summit eruption in April 2011.

During 2010, NEPTUNE Canada, a fiber-optic cabled node of deep-sea sensors deployed along the northern Juan de Fuca Ridge, became operational (Barnes and Tunnicliffe, 2008). The node's seismometers and hydrophones are deployed on and off the ridge axis. The acoustic phases of hundreds of earthquakes from the ridge and nearby transforms have been recorded to date.

International Monitoring System

During the late 1990s, a global real-time system of radionuclide, seismic, infrasound, and hydroacoustic sensors was constructed to support a Comprehensive Nuclear Test Ban. This infrastructure is collectively known as the International Monitoring System (IMS; Figure 3). The hydroacoustic component consists of five island-based seismic stations and six cabled hydrophone installations at Diego Garcia, Cape Lueewin, and Crozet Island in the Indian Ocean; Juan Fernandez and Wake Islands in the Pacific; and Ascension Island in the Atlantic. Each hydrophone station hosts a set of three sound-channel moored sensors deployed as a small-aperture (~ 2 km) horizontal array, allowing the direction of incoming acoustic energy to be determined and therefore enhancing the location capabilities afforded by the relatively sparse network.

Hanson and Bowman (2005) used *T*-phases recorded on the IMS stations in the Indian Ocean to locate 1,146 earthquakes from the Central and Southeast Indian Ridges during a 10-month period in 2003. The Indian Ocean *T*-phase seismicity clustered at ridge-transform intersections, with several gaps in earthquake activity occurring within ridge segments. Other projects have used *T*-phase seismicity to study the diffuse nature of the plate boundary system along the Indian Ocean spreading centers and the organization of transform faults within the basin (e.g., Bohnenstiehl et al., 2004b; Yun et al., 2009).

THE FUTURE OF MID-OCEAN RIDGE MONITORING

It is interesting to speculate upon what developments will occur in deep-ocean acoustic monitoring. Recent improvements in autonomous underwater vehicle (AUV) technology will lead to the next significant advancement in hydroacoustic monitoring. A recent example occurred when an ocean glider capable of satellite data transmission was flown around an erupting volcano with a hydrophone in its payload (Matsumoto et al., 2011). One can envision a constellation of gliders or autonomous floats (e.g., Simons et al., 2009) circling large regions of the world's MORs, screening acoustic signals for volcano-tectonic seismicity and reporting on the latest eruption or seafloor spreading event.

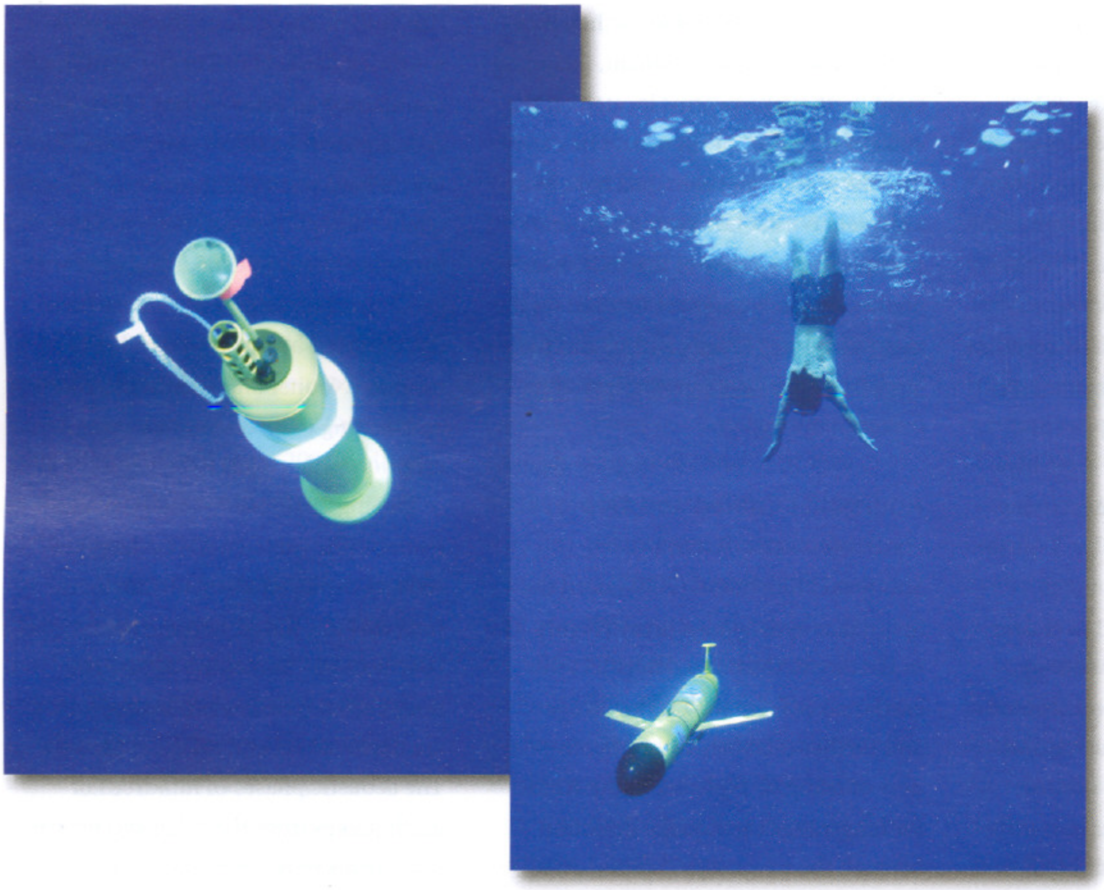

Figure 5. (Left) Image of quasi-Eulerian autonomous hydrophone (Que-phone) float. The Que-phone self controls buoyancy and can perform several ascent/descent cycles to survey the ocean sound field from seafloor to sea surface. (Right) Image of an ocean glider (Webb Research Inc.) with a hydrophone and recording package mounted on the platform (Matsumoto et al., 2011). The glider is capable of a more structured survey methodology and can vertically and laterally survey the water column over a several tens of square kilometers. Haru Matsumoto is shown for scale.

Within the next few years, the US Regional Scale Nodes, a counterpart to the NEPTUNE Canada initiative, will instrument portions of the Juan de Fuca Ridge. The Axial Volcano node will include an array of seafloor seismometers and at least one hydrophone moored in the water column. These systems will enable real-time, in situ, seismo-acoustic monitoring of ridge-crest volcanic activity, albeit a spatially limited view of Northeast Pacific spreading center dynamics.

Ocean glider and AUV technology will continue to improve in both physical maneuverability and the quality and amount of data collected (Figure 5). Perhaps future developments will allow for deployment of a shoal of platforms with multiple hydrophones, which can beamform and localize acoustic sources while at sea. The instruments will then transmit their findings in real time back to shore-based researchers via satellite. Undoubtedly, future military assets will improve on the capability of the current SOSUS hydrophone system, and we optimistically envision a future military-civilian, dual-use program where the latest technology will be available to the ocean science community for deep-ocean research.

SUMMARY

Over the last 84 years since hydroacoustic *T*-phases were first discovered, there have been profound advances in our understanding of the physical means by which *T*-phases are generated, how they propagate, the variety of volcano-tectonic settings where they are created, and the hydroacoustic technologies used to detect them. This paper focused on the acoustic phases detected from mid-ocean ridges and how this information was used to provide insight into spreading center processes. Given the expected improvements in global, deep-ocean monitoring technologies during the next century, we foresee a time when even a segment-scale magmatic or seafloor spreading event will be detected as it happens anywhere in the deep ocean.

ACKNOWLEDGEMENTS

The authors wish to thank M. Tolstoy, J. Perrot, E. Hooft, and E. Kappel for very insightful comments that improved the manuscript. SOSUS studies discussed in this paper were supported by the NOAA Vents Program and during 2006–2009 by the National Science Foundation, Grant OCE-0623649. This paper is PMEL contribution number 3746.

REFERENCES

Baker, E.T., G.J. Massoth, R.A. Feely, R.W. Embley, R.E. Thomson, and B.J. Burd. 1995. Hydrothermal event plumes from the CoAxial seafloor eruption site, Juan de Fuca Ridge. *Geophysical Research Letters* 22(2):147–150, http://dx.doi.org/10.1029/94GL02403.

Bath, M., and M. Shahidi. 1971. *T*-phases from Atlantic earthquakes. *Pure and Applied Geophysics* 92:74–114, http://dx.doi.org/10.1007/BF00874995.

Bath, M. 1954. Study of *T*-phases recorded at the Kiruna seismograph station. *Tellus* 6(1):63–72.

Barnes, C., and V. Tunnicliffe. 2008. Building the world's first multi-node cabled ocean observatories (Neptune Canada and VENUS, Canada): Science, realities, challenges, and opportunities. Pp. 1–8 in *Oceans 2008: MTS/IEEE Kobe Techno-Ocean*. http://dx.doi.org/10.1109/OCEANSKOBE.2008.4531076.

Blackman, D.K., C.E. Nishimura, and J.A. Orcutt. 2000. Seismoacoustic recordings of a spreading episode on the Mohns Ridge. *Journal of Geophysical Research* 105(B5):10,961–10,973, http://dx.doi.org/10.1029/2000JB900011.

Bohnenstiehl, D.R., R.P. Dziak, H. Matsumoto, A. Lau, M. Fowler, K.E. Cook, C.M. Scheip, K.W. Warren, J.A. Conder, and D.A. Wiens. 2010. Hydroacoustic monitoring of seismic and volcanic activity within the Lau Basin. *Eos, Transactions, American Geophysical Union* 90(52):Fall Meeting Abstract T11E-02.

Bohnenstiehl, D.R., R.P. Dziak, M. Tolstoy, C. Fox, and M. Fowler. 2004. Temporal and spatial history of the 1999–2000 Endeavour Segment seismic series, Juan de Fuca Ridge. *Geochemistry Geophysics Geosystems* 5, Q09003, http://dx.doi.org/10.1029/2004GC000735.

Bohnenstiehl, D.R., and M. Tolstoy. 2003. Comparison of teleseismically and hydroacoustically derived earthquake locations along the north-central Mid-Atlantic Ridge and equatorial East-Pacific Rise. *Seismological Research Letters* 74:790–801, http://dx.doi.org/10.1785/gssrl.74.6.791.

Bohnenstiehl, D.R., M. Tolstoy, and E. Chapp. 2004. Breaking into the plate: A 7.6 M_w fracture-zone earthquake adjacent to the Central Indian Ridge. *Geophysical Research Letters* 31, http://dx.doi.org/10.1029/2003GL018981.

Bohnenstiehl, D.R., M. Tolstoy, R.P. Dziak, C.G. Fox and D.K. Smith. 2002. Aftershock sequences in the mid-ocean ridge environment: An analysis using hydroacoustic data. *Tectonophysics* 354:49–70, http://dx.doi.org/10.1016/S0040-1951(02)00289-5.

Brocher, T.M. 1983. *T*-phases from an earthquake swarm on the Mid-Atlantic Ridge at 31.6°N. *Marine Geophysical Researches* 6(1):39–49, http://dx.doi.org/10.1007/BF00300397.

Collins, M.P. 1936. *Bulletin Number 5*. Harvard University Seismograph Station, 23 pp.

Cooke, R.J.S. 1967. Observations of the seismic T-phase at Macquarie Island. *New Zealand Journal of Geology and Geophysics* 10:1,212–1,225.

Crane, K., L. Johnson, B. Appelgate, C. Nishimura, R. Buck, C. Jones, P. Vogt, and R. Kos'yan. 1997. Volcanic and seismic swarm events on the Reykjanes Ridge and their similarities to events on Iceland: Results of a rapid response mission. *Marine Geophysical Researches* 19(4):319–338, http://dx.doi.org/10.1023/A:1004298425881.

deMartin, B.J., R.A. Sohn, J.P. Canales, S.E. Humphris. 2007. Kinematics and geometry of active detachment faulting beneath the Trans-Atlantic Geotraverse (TAG) hydrothermal field on the Mid-Atlantic Ridge. *Geology* 35(8):711–714, http://dx.doi.org/101130/G23718A.1.

Dziak, R.P., D.R. Bohnenstiehl, J.P. Cowen, E.T. Baker, K.H. Rubin, J.H. Haxel, and M.J. Fowler. 2007. Rapid dike emplacement leads to eruptions and hydrothermal plume release during seafloor spreading events. *Geology* 35(7):579–582, http://dx.doi.org/10.1130/G23476A.1.

Dziak, R.P, D.R. Bohnenstiehl, H. Matsumoto, M.J. Fowler, J.H. Haxel, M. Tolstoy, and F. Waldhauser. 2009. The January 2006 seafloor spreading event at 9°50′N, East Pacific Rise: Ridge dike intrusion and transform fault interactions from regional hydroacoustic data. *Geochemistry Geophysics Geosystems* 10, Q06T06, http://dx.doi.org/10.1029/2009GC002388.

Dziak, R.P., D.R. Bohnenstiehl, H. Matsumoto, C.G. Fox, D.K. Smith, M. Tolstoy, T.-K. Lau, J.H. Haxel, and M.J. Fowler. 2004a. *P*- and *T*-wave detection thresholds, *Pn* velocity estimate, and detection of lower mantle and core *P*-waves on ocean sound channel hydrophones at the Mid-Atlantic Ridge. *Bulletin of the Seismological Society of America* 94:665–677, http://dx.doi.org/10.1785/0120030156.

Dziak, R.P., W.W. Chadwick, C.G. Fox, and R.W. Embley. 2003. Hydrothermal temperature changes at the southern Juan de Fuca Ridge associated with the M_w 6.2 Blanco Transform earthquake. *Geology* 31(2):119–122, http://dx.doi.org/10.1130/0091-7613(2003)031<0119:HTCATS>2.0.CO;2.

Dziak, R.P., C.G. Fox, R.W. Embley, J.E. Lupton, G.C Johnson, W.W. Chadwick, and R.A. Koski. 1996. Detection of and response to a probable volcanogenic *T*-wave event swarm on the western Blanco Transform Fault Zone. *Geophysical Research Letters* 23(8):873–876, http://dx.doi.org/ 10.1029/96GL00240.

Dziak, R.P., and C.G. Fox. 1999. The January 1998 earthquake swarm at Axial Volcano, Juan de Fuca Ridge: Hydroacoustic evidence of seafloor volcanic activity. *Geophysical Research Letters* 26(23):3,429–3,432, http://dx.doi.org/10.1029/1999GL002332.

Dziak, R.P., C.G. Fox, and A.E. Schreiner. 1995. The June-July seismo-acoustic event at CoAxial segment, Juan de Fuca Ridge: Evidence for lateral dike injection. *Geophysical Research Letters* 22(2):135–138, http://dx.doi.org/10.1029/94GL01857.

Dziak, R.P., M. Park, W.-S. Lee, H. Matsumoto, D.R. Bohnenstiehl, and J.H. Haxel. 2010. Tectonomagmatic activity and ice dynamics in the Bransfield Strait back-arc basin, Antarctica. *Journal of Geophysical. Research* 115, B01102, http://dx.doi.org/10.1029/2009JB006295.

Dziak, R.P., D.K. Smith, D.R. Bohnenstiehl, C.G. Fox, D. Desbruyeres, H. Matsumoto, M. Tolstoy, and D.J. Fornari. 2004b. Evidence of a recent magma dike intrusion at the slow spreading Lucky Strike segment, Mid-Atlantic Ridge. *Journal of Geophysical Research* 109, B12102, http://dx.doi.org/10.1029/2004JB003141.

Edwards, M.H., G.J. Kurras, M. Tolstoy, D.R. Bohnenstiehl, B.J. Coakley, and J.R. Cochran. 2001. Evidence of recent volcanic activity on the ultraslow-spreading Gakkel Ridge. *Nature* 409:808–812: http://dx.doi.org/10.1038/35057258.

Embley, R.W., W.W. Chadwick Jr., I.R. Jonasson, D.A. Butterfield, and E.T. Baker. 1995. Initial results of a rapid response to the 1993 CoAxial event: Relationships between hydrothermal and volcanic processes. *Geophysical Research Letters* 22(2): 143–146, http://dx.doi.org/10.1029/94GL02281.

Escartín, J., D.K. Smith, J. Cann, H. Schouten, C.H. Langmuir, and S. Escrig. 2008. Central role of detachment faults in accretion of slow-spreading lithosphere. *Nature* 455:790–794, http://dx.doi.org/10.1038/nature07333.

Ewing, W.M., G.P. Woollard, V.C. Vine, and J.L. Worzel. 1946. Recent results in submarine geophysics. *Geology Society of America* 40:53–58, http://dx.doi.org/10.1130/0016-7606(1946)57[909:RRISG]2.0.CO;2.

Ewing, W.M., and J.L. Worzel. 1948. *Long-Range Sound Transmission*. Geological Society of America Memoir 27(3), 39 pp.

Fox, C.G., and R.P. Dziak. 1998. Hydroacoustic detection of volcanic activity on the Gorda Ridge, February–March 1996. *Deep Sea Research Part II* 45(12):2,513–2,530, http://dx.doi.org/10.1016/S0967-0645(98)00081-2.

Fox, C.G., R.P. Dziak, H. Matsumoto, and A.E. Schreiner. 1994. Potential for monitoring low-level seismicity on the Juan de Fuca Ridge using military hydrophone arrays. *Marine Technology Society Journal* 27(4):22–30.

Fox, C.G., and S.R. Hammond. 1994. The VENTS Program *T*-phase project and NOAA's role in ocean environmental research. *Marine Technology Society Journal* 27(4):70–74.

Fox, C.G., H. Matsumoto, and T.-K. Lau. 2001. Monitoring Pacific Ocean seismicity from an autonomous hydrophone array. *Journal of Geophysical Research* 106:4,183–4,206, http://dx.doi.org/10.1029/2000JB900404.

Fox, C.G., W.E. Radford, R.P. Dziak, T.-K. Lau, H. Matsumoto, and A.E. Schreiner. 1995. Acoustic detection of a seafloor spreading episode on the Juan de Fuca Ridge using military hydrophone arrays. *Geophysical Research Letters* 22(2):131–134, http://dx.doi.org/10.1029/94GL02059.

Goslin, J., N. Lourenzo, R.P. Dziak, D.R. Bohnenstiehl, J. Haxel, and J. Luis. 2005. Long-term seismicity of the Reykjanes Rift (North Atlantic) recorded by a regional hydrophone array. *Geophysical Journal International* 162(2):516–524, http://dx.doi.org/10.1111/j.1365-246X.2005.02678.x.

Hammond, S.R., and D.A. Walker. 1991. Ridge event detection: *T*-phase signals from the Juan de Fuca spreading center. *Marine Geophysical Researches* 13:331–348, http://dx.doi.org/10.1007/BF00366282.

Hanson, J.A., and J.R. Bowman. 2005. Indian Ocean Ridge seismicity observed with a permanent hydroacoustic network. *Geophysical Research Letters* 32, L06301, http://dx.doi.org/10.1029/2004GL021931.

Haxel, J.H., R.P. Dziak, H. Matsumoto, M.J. Fowler, and W.W. Chadwick Jr. 2011. A time history of micro-seismicity leading to volcanic eruption at Axial Volcano, Juan de Fuca Ridge. *Eos, Transactions, American Geophysical Union*, Fall Meeting Abstract V14C-06.

Holden, J.F., M. Summit, and J.A. Baross. 1998. Thermophilic and hyperthermophilic microorganisms in 3–30°C hydrothermal fluids following a deep-sea volcanic eruption. *FEMS Microbiology Ecology* 25:33–41, http://dx.doi.org/10.1111/j.1574-6941.1998.tb00458.x.

Hooft, E.E.E., H. Patel, W. Wilcock, K. Becker, D. Butterfield, E. Davis, R. Dziak, K. Inderbitzen, M. Lilley, P. McGill, and others. 2010. A seismic swarm and regional hydrothermal and hydrologic perturbations: The northern Endeavour Segment, February 2005. *Geochemistry Geophysics Geosystems* 11, Q12015, http://dx.doi.org/10.1029/2010GC003264.

Jagger, T.A. 1930. How the seismograph works. *The Volcano Letter* 268:1–4.

Johnson, R.H., R.A. Norris, and F.K. Duennebier. 1968. Abyssally generated *T*-phases. Pp. 70–78 in *The Crust and Upper Mantle of the Pacific Area*. L. Knopoff, C.L. Drake, and P.J. Hart, eds, American Geophysical Union Monograph Series Volume 12, Washington, DC, http://dx.doi.org/1010.1029/GM012p0070.

Johnson, R.H., J. Northrop, and R. Epply. 1963. Sources of Pacific *T*-phases. *Journal of Geophysical Research* 68:4,251–4,261.

Keenan, R.E., and I. Dyer. 1984. Noise from Arctic Ocean earthquakes. *Journal of the Acoustical Society of America* 75(3):819–825, http://dx.doi.org/10.1121/1.390591.

Keenan, R.E., and L.R.L. Merriam. 1991. Arctic abyssal *T* phases: Coupling seismic energy to the ocean sound channel via under-ice scattering. *Journal of the Acoustical Society of America* 89(3):1,128–1,133, http://dx.doi.org/10.1121/1.400648.

Kristoffersen, Y., E.S. Husebye, H. Bungum, and S. Gregersen. 1982. Seismic investigations of the Nansen Ridge during the FRAM I experiment. *Tectonophysics* 82(1):57–68, http://dx.doi.org/10.1016/0040-1951(82)90088-9.

Kong, L.S.L., S.C. Solomon, and G.M. Purdy. 1992. Microearthquake characteristics of a mid-ocean ridge along-axis high. *Journal of Geophysical Research* 97(B2):1,659–1,685, http://dx.doi.org/10.1029/91JB02566.

Linehan, J. 1940. Earthquakes in the West Indian region. *Eos, Transactions, American Geophysical Union* 21:229–232.

Macdonald, K.C., and J.D. Mudie. 1974. Microearthquakes on the Galapagos spreading centre and the seismicity of fast-spreading ridges. *Geophysical Journal International* 36(2):245–257, http://dx.doi.org/10.1111/j.1365-246X.1974.tb03636.x.

Matsumoto, H., J. H. Haxel., R.P. Dziak, D.R. Bohnenstiehl, and R.W. Embley. 2011. Mapping the sound field of an erupting submarine volcano using an acoustic glider. *Journal of the Acoustical Society of America* 129(3):94–99, http://dx.doi.org/10.1121/1.3547720

Merle, S.M., R.P. Dziak, R.W. Embley, W.W. Chadwick Jr., J.E. Lupton, D.R. Bohnenstiehl, J. Braunmiller, R. Greene, and M. Fowler. 2008. Preliminary analysis of multibeam, subbottom, and water column data collected from the Juan de Fuca and Gorda Ridge earthquake swarm sites, March-April 2008. *Eos, Transactions, American Geophysical Union* 88: Fall Meeting Abstract T23B-2025.

Nishimura, C.E., and D. Conlon. 1994. IUSS dual use: Monitoring whales and earthquakes using SOSUS. *Marine Technology Society Journal* 27(4):13–21.

Nooner, S.L., and W.W. Chadwick Jr. 2009. Volcanic inflation measured in the caldera of Axial Seamount: Implications for magma supply and future eruptions. *Geochemistry Geophysics Geosystems* 10, Q02002, http://dx.doi.org/10.1029/2008GC002315.

Northrop, J. 1970. Accuracy of earthquake epicenters on the Gorda ridge. *Bulletin of the Seismological Society of America* 60(1):265–267.

Northrop, J., H.W. Menard, and F.K. Duennebier. 1968. Seismic and bathymetric evidence of a fracture zone on the Gorda Ridge. *Science* 161:688–690, http://dx.doi.org/10.1126/science.161.3842.688.

Okal, E.A. 2008. The generation of *T* waves by earthquakes. *Advances in Geophysics* 49:1–65, http://dx.doi.org/10.1016/S0065-2687(07)49001-X.

Pan, J., and A.M. Dziewonski. 2005. Comparison of mid-oceanic earthquake epicentral differences of travel time, centroid locations, and those determined by autonomous underwater hydrophone arrays. *Journal of Geophysical Research* 110, B07302, http://dx.doi.org/10.1029/2003JB002785.

Reid, I., and K. Macdonald. 1973. Microearthquake study of the Mid-Atlantic Ridge near 37°N using sonobuoys. *Nature* 246:88–90, http://dx.doi.org/10.1038/246088a0.

Reid, I., M. Reichle, J. Brune, and H. Bradner. 1973. Microearthquake studies using sonobuoys: Preliminary results from the Gulf of California. *Geophysical Journal International* 34(3):365–379, http://dx.doi.org/10.1111/j.1365-246X.1973.tb02401.x.

Royer, J-Y, R.P. Dziak, M. Delatre, C. Brachet, J.H. Haxel, H. Matsumoto, J. Goslin, V. Brandon, D.R. Bohnenstiehl, C. Guinet, and F. Samaran. 2008. Preliminary results from an hydroacoustic experiment in the Indian Ocean. *Eos, Transactions, American Geophysical Union* 88:Fall Meeting Supplement Abstract T51B-1883.

Schlindwein, V., C. Muller, and W. Jokat. 2005. Seismoacoustic evidence for volcanic activity on the ultra-slow spreading Gakkel Ridge, Arctic Ocean. *Geophysical Research Letters* 32, L18306, http://dx.doi.org/10.1029/2005GL023767.

Schreiner, A.E., C.G. Fox, and R.P. Dziak. 1995. Spectra and magnitudes of *T*-waves from the 1993 earthquake swarm on the Juan de Fuca Ridge. *Geophysical Research Letters* 22(2):139–142, http://dx.doi.org/10.1029/94GL01912.

Simao, J., J. Escartín, J. Goslin, M. Haxel, M. Cannat, and R. Dziak. 2010. Regional seismicity of the Mid-Atlantic Ridge: Observations from an autonomous hydrophone array. *Geophysics Journal International* 183(3):1,559–1,578 http://dx.doi.org/10.1111/j.1365-246X.2010.04815.x.

Simons, F.J., G. Nolet, P. Georgief, J.M. Babcock, L.A. Regier, and R.E. Davis. 2009. On the potential of recording earthquakes for global seismic tomography by low-cost autonomous instruments in the oceans. *Journal of Geophysical Research* 114, B05307, http://dx.doi.org/10.1029/2008JB006088.

Slack, P.D., C.G. Fox, and R.P. Dziak. 1999. *P*-wave detection thresholds, *Pn* velocity estimates, and *T* wave location uncertainty from oceanic hydrophones. *Journal of Geophysical Research* 104:13,061–13,072, http://dx.doi.org/10.1029/1999JB900112.

Sohn, R.A., W.C. Crawford, and S.C. Webb. 1999. Local seismicity following the 1998 eruption of Axial Volcano. *Geophysical Research Letters* 26(23):3,433–3,436, http://dx.doi.org/10.1029/1999GL900505.

Sohn, R.A., and J.A. Hildebrand. 2001. Hydroacoustic earthquake detection in the Arctic Basin with the Spinnaker Array. *Bulletin of the Seismological Society of America* 91(3):572–579, http://dx.doi.org/10.1785/0120000099.

Smith, D.K., J. Escartín, M. Cannat, M. Tolstoy, C.G. Fox, D.R. Bohnenstiehl, and S. Bazin. 2003. Spatial and temporal distribution of seismicity along the northern Mid-Atlantic Ridge (15°–35°N). *Journal of Geophysical Research* 108(B3), 2167, http://dx.doi.org/10.1029/2002JB001964.

Smith, D.K., M. Tolstoy, C.G. Fox, D.R. Bohnenstiehl, H. Matsumoto, and M.J. Fowler. 2002. Hydroacoustic monitoring of seismicity at the slow-spreading Mid-Atlantic Ridge. *Geophysical Research Letters* 29(11), 1518, http://dx.doi.org/10.1029/2001GL013912.

Spindel, R.C., S.B. Davis, K.C. Macdonald, R.P. Porter, and J.D. Phillips. 1974. Microearthquake survey of the median valley of the Mid-Atlantic Ridge at 36°30'N. *Nature* 248:577–579, http://dx.doi.org/10.1038/248577a0.

Tolstoy, I., and M. Ewing. 1950. The *T*-phase of shallow-focus earthquakes. *Bulletin of the Seismological Society of America* 40:25–51.

Tolstoy, M., J.P. Cowen, E.T. Baker, D.J. Fornari, K.H. Rubin, T.M. Shank, F. Walderhauser, D.R. Bohnenstiehl, D.W. Forsyth, and R.C. Holmes. 2006. A sea-floor spreading event captured by seismometers. *Science* 314(587):1,920–1,922, http://dx.doi.org/10.1126/science.1133950.

Toomey, D., S.C. Solomon, G.M. Purdy, and M.H. Murray. 1985. Microearthquakes beneath the median valley of the mid-Atlantic Ridge near 23°N: Hypocenters and focal mechanisms. *Journal of Geophysical Research* 90(B7):5,443–5,458, http://dx.doi.org/10.1029/JB090iB07p05443.

Walker, D.A., and S.R. Hammond. 1998. Historical Gorda Ridge *T*-phase swarms: Relationships to ridge structure and the tectonic and volcanic state of the ridge during 1964–1966. *Deep Sea Research Part II* 45:2,531–2,545, http://dx.doi.org/10.1016/S0967-0645(98)00082-4.

Yun, S., S. Ni, M. Park, and W.S. Lee. 2009. Southeast Indian Ocean-Ridge earthquake sequences from cross-correlation analysis of hydroacoustic data. *Geophysical Journal International* 179:401–407, http://dx.doi.org/10.1111/j.1365-246X.2009.04292.x.