Figure F1. Location map of the Philippine Sea region. The Izu-Bonin and Mariana arcs and associated trenches form the eastern boundary of the Philippine Sea plate. The western boundary includes the Ryukyu-Kyushu and Philippine arcs and trenches. Back-arc basins such as the Shikoku Basin, Parece Vela Basin, and Mariana Trough were created by seafloor spreading between the formerly contiguous remnant arc (Kyushu-Palau and West Mariana Ridges) and eastward-migrating active volcanic arcs, now represented by the Izu-Bonin and Mariana arcs. Site U1438 (pink star) is in the Amami Sankaku Basin.

Figure F2. Track map of multichannel seismic survey Lines D98-A and D98-8. Site U1438 is located at the intersection of the two lines.

Figure F3. Seismic reflection images, Site U1438. Top two panels comprise MCS Line D98-8 (upper) and interpreted major reflectors (lower). Bottom two panels show MCS Line D98-A (upper) and interpreted major reflectors (lower).

Figure F4. Hole configuration, Site U1438.

Figure F5. Lithostratigraphic overview of Site U1438, including sediment and sedimentary rock lithostratigraphic Units I–IV and oceanic igneous basement Unit 1. Maximum bedding thickness corresponds to the thickest graded bed present in each core as determined by visual observation: *** = >1 m, ** = 1–0.3 m, * = <0.3 m. # = no reliable estimates because of unconsolidated sediment, drilling disturbance, and/or faulting. Bed width corresponds to the average grain size averaged over 5 m bins. Average grain size is for 5 m thick intervals. Owing to 5 m bin size, features on the order of core section length may not be evident. Grain size classes: Cl = clay, Si = silt, Vfs–fs = very fine and fine sand, Ms–vcs = medium to very coarse sand, Gr = granules.

Figure F6. Downhole plots of modal grain size, degree of bioturbation, sedimentary structures and bedding orientation, using data from Holes U1438B and U1438D. Characteristics were averaged over 2 m intervals, which may mask features on the order of core section length.

Figure F7. Overview of component proportions for Units I and II based on smear-slide data (see Smear slides in **Core descriptions**).

Figure F8. Upper contact between tuffaceous foraminifer ooze layers and overlying mud in correlative beds in Holes U1438A (left) and U1438B (right). Note the soupy texture of the ooze in each core and the large dark scoria clast in the Hole U1438B deposit.

Figure F9. Lower part of Unit I. Left: light-colored ash pods in a variegated, bioturbated mud. Right: lighter ash layer with a sharp basal contact with underlying dark brown mud, which grades into slightly bioturbated tuffaceous mud and then moderately bioturbated mud.

Figure F10. X-ray diffractograms for mud lithologies in cores through Unit I, Hole U1438B. Prominent peaks include quartz (Qz), plagioclase (P), muscovite + illite (M + I), chlorite (C), chlorite + zeolite minerals (C & Z), and calcite (Ca), which produce a broad peak at low 2θ angles for many samples collected in Cores 351-U1438B-11H through 17H.

Figure F11. Intensity of quartz peaks at 26.6°2θ for Unit I mud samples, Hole U1438B. The downhole decrease in variability and intensity of quartz peaks in XRD scans correspond to downhole changes in the color of Unit I mud and the transition from hemipelagic mud to deep-sea clay.

Figure F12. Core and smear slide images for selected ash intervals, Hole U1438B. Top: left, thin light gray ash bed (19 cm) grades into shallower darker tuffaceous mud underlain by gray mud (8H-3A, 13–19 cm). Right, ash (14–15 cm) has blocky glass shards and pumice fragments. Note glass fragment size may have been artificially modified by grain crushing during smear slide production. Middle: left, dark ash lamina (8H-2A, 22–25 cm) at 24–25 cm; right shows green clinopyroxene and feldspar-bearing mafic to intermediate ash with both darker brown mafic vitric shards (center) and colorless glass. Bottom: left, light gray ash (14H-4A, 140–141 cm) shows right, large brown biotite crystals and colorless glass shards. All photomicrographs taken in plane polarized light (PPL).

Figure F13. Correlation between the first three cores in Holes U1438A and U1438B created by visual inspection of core images. Selected ash-bearing and foraminifer/nannofossil intervals are correlated where determined to be similar in appearance, composition, and texture.

Figure F14. Bedding/lamination features in unconsolidated tuffaceous sediments from Unit II, Hole U1438B. Left: normally graded tuffaceous silt to sand layer at 4–10 cm marks the boundary between Units I and II. Right: two graded intervals comprise tuffaceous mud to fine sand.

Figure F15. Normally graded sandstone–mudstone bed with bioturbated top.

Figure F16. Bedding/lamination features in tuffaceous siltstones, sandstones, and breccia-conglomerates from Unit II, Holes U1438B and U1438D. Top left: cross-laminated fine tuffaceous sandstone grades downward into coarse poorly consolidated tuffaceous sandstone (20–40 cm). Bottom left: soft-sediment deformation features in tuffaceous siltstone (88–99 cm). Right: tuffaceous coarse sandstone to breccia-conglomerate “biscuits” (0–22 cm) overlie bioturbated tuffaceous mudstone.

Figure F17. Two crystal-vitric tuff layers in Unit II, Hole U1438B.

Figure F18. Left: Fining-upward white tuff at 88–99 cm with a sharp bottom contact. Notice the strong bioturbation of the overlying tuffaceous mudstone and the scoured contact at the base of the darker tuffaceous sandstone. Top right: Vitric-rich (70% vitric glass) tuffaceous siltstone. Middle right: Upper finer grained vitric tuff seen in left image. Bottom right: White vitric tuff from left image shows coarse-grained vitric glass and crystals, feldspar (Feld), and hornblende (Hbld). All photomicrographs taken in PPL.

Figure F19. Schematic column and structural features for the lower part of Hole U1438B (24X–30X) and upper part of Hole U1438D (2R–12R). Two arrows show the position of key beds (dark gray tuffaceous sandstone and pale red ash). Zones enclosed by blue lines indicate deformed or slightly deformed zones.

Figure F20. Key correlative marker beds in cores from Holes U1438B and U1438D, characterized by a pair of dark gray tuffaceous sandstone and pale red ash layers intercalated with moderately bioturbated tuffaceous mudstone.

Figure F21. Steeply inclined beds of tuffaceous mudstone with normal and reverse microfaults.

Figure F22. Southwest–northeast seismic section through the Site U1437 highlighting a putative fault showing offset of apparent bedding (from Japan National Oil Corporation, 1998).

Figure F23. Features of Unit III tuffaceous mudstones and siltstones. Left: three sequences of planar laminated fine sandstone to siltstone, overlain by cross-laminated siltstone, overlain by bioturbated mudstone. Middle: thin laminated sandstone/siltstone layer, overlain by cross-laminated siltstone and bioturbated mudstone. Right: laminated fine sandstone and siltstone with dewatering structures.

Figure F24. Features in Unit IV siltstone and mudstones. Top: authigenic spheres composed of zeolites and magnetite in siltstone. Bottom: alternating red and dark green layers in siltstones and mudstones (PPL).

Figure F25. Estimated volume of tuffaceous sandstone components in thin section. Left: total components in sandstone. Right: simplified volume estimation without grain size <silt, pores, and cement materials. Phenocrysts in volcanic clasts are counted as "clast." Fine, medium, and coarse sands are included, but gravel is excluded.

Figure F26. Top: monomict clast-supported tuffaceous breccia conglomerate with pumice clasts. Bottom: polymict clast-supported tuffaceous breccia conglomerate with clasts of holocrystalline volcanic rock, scoria, and pumice.

Figure F27. Top: A single 3 cm thick mafic lapillistone. Bottom left: lapillistone (PPL). Bottom right: same view as in bottom left but between crossed polars (XPL) which illustrates that lapilli are replaced by a brown clay mineral and zeolite (see **Veins and alteration**).

Figure F28. Common types of clasts in Unit III breccia-conglomerates (PPL, left), (XPL, right). Top: pumice clasts. Middle: black and gray volcanic rock clasts, with fresh plagioclase, pyroxene, and oxide (opaque) phenocrysts. Bottom: clast with euhedral inclusion-bearing hornblende phenocrysts, together with plagioclase.

Figure F29. Alteration features in breccia-conglomerate clasts and matrix in the deeper cores of Unit III (PPL, left), (XPL, right). Top: green clay mineral cementation (note rims on grains) and replacement of some mineral grains with green clay. Middle: pumice clasts in a breccia-conglomerate completely replaced by anhydrite. Bottom: breccia-conglomerate matrix, clast groundmass, and a former ferromagnesian mineral, possibly olivine, are largely replaced by chlorite and zeolites, plagioclase is partially replaced by zeolites, and clinopyroxene is relatively unaltered.

Figure F30. Left: 9 cm thick mafic tuffaceous sandstone or tuff bed with a sharp bottom contact and gradational upper contact into tuffaceous mud. Top right: aphyric and porphyritic coarse ash grains in zeolite-dominated matrix (PPL). Bottom right: aphyric coarse ash grain dominated by oriented euhedral feldspar microphenocrysts (PPL).

Figure F31. Key marker beds associated with the correlation between the bottom of Hole U1438D and the top of Hole U1438E. Correlations are based on patterns in MS, NGR intensity, and visual inspection of key beds.

Figure F32. Hole U1438E, Unit IV. A, B. Tuffaceous sandstone (64R-4; B: PPL) shows mafic and pumiceous lithic sand grains and volcanic mineral grains (arrow). C, D. Tuffaceous breccia-conglomerate (62R-2; D: XPL) shows abundant radiolarians in a mudstone clast. E, F. Tuffaceous breccia-conglomerate (351-U1438E-63R-2; F: PPL) shows a mudstone clast (left) in contact with sand-sized lithic fragments, mineral grains, and radiolarians (arrow). Scale bars = 1 mm.

Figure F33. Hole U1438E, Unit IV, igneous rock (top; 61R-2, TS-93; XPL) compared to basement basalt (bottom; 75R-1, TS-111; XPL) at the same scale. Phenocrysts in the Unit IV igneous rocks are pyroxene only. Note also the fine groundmass and absence of plagioclase. All Unit IV igneous rocks share these petrographic characteristics.

Figure F34. Igneous textures in Unit 1 basaltic rocks (XPL, left). (PPL, right).

Figure F35. Unit 1 basalts, Hole U1438E. Top left: chrome spinel (80R-1W; 1534.53 mbsf; PPL). Top right: olivine replaced by calcite (84R-1W; 1571.94 mbsf; PPL). Bottom left: quench textures in basalt (75R-1; 1504.33 mbsf; XPL). Bottom right: alteration of basalts (83R-2W; 1563.97 mbsf; XPL).

Figure F36. Sheet flow base contact in Unit 1 (351-U1438E-83R-1A, 14–40 cm). Grain size changes gradationally from flow interior (microcrystalline) to flow base (cryptocrystalline). Cooling joints also developed at flow base and show oxidized halos by secondary alteration.

Figure F37. Chilled margins in Unit 1 (oceanic igneous basement), Hole U1438E. Left: chilled margin with decrease in grain size toward the flow contact. Right: flow contact with altered glassy matrix and spherulitic microphenocrysts.

Figure F38. Summed peak counts, Holes U1438B and U1438D. Maximum counts for peaks between 9° and 18°2θ identified by the Bruker Diffraction Evaluation software were summed for seven common zeolite groups and related minerals identified in X-ray diffractograms from Unit II and III samples. Five of the peaks fall between 9.3° and 9.9°2θ (laumontite, chabazite, stilbite, heulandite, and clinoptilolite), and there are additional peaks at 12.4° (phillipsite) and 15.8° (analcite).

Figure F39. Downhole changes in green-red reflectance (a*) measured by the SHMSL (0.6 m running average) and modal grain size from the core logs. Red alteration zones at base of hole affect only fine-grained rocks.

Figure F40. Coarse inclusions/veins of hydrothermal minerals in Unit 1 basalts.

Figure F41. Summary of microfossil information, Holes U1438B and U1438D. "Barren" refers to marker species.

Figure F42. Biostratigraphic and paleomagnetic age-depth plot against lithostratigraphic units, Site U1438. Ages based on the Gradstein et al. (2012) timescale.

Figure F43. SEM (upper) and reflected light (lower) images of *Acarinina* sp. (Sample 351-U1438E-66R-CC).

Figure F44. Scanning Electron Microscope pictures of radiolarians from Hole U1438E (Sample 63R-1W, 23–25 cm; early Eocene): 1, 2. *Buryella tetradica*; 3, 4. *Calocycloma castum*; 5. *Lamptonium fabaeforme*; 6. *Phormocyrtis* cf. *striata exquisita*; 7. *Theocotylissa ficus*; 8. *Theocotyle nigrinae*. (Sample 63R-1W, 78–81 cm; latest Paleocene–early Eocene): 9. *Buryella* sp.; 10. *Phormocyrtis* sp.; 11. *Podocyrtis* sp.; 12. *Theocotylissa* sp.

Figure F45. Alkalinity, pH, redox potential, sulfate, phosphate, and ammonium depth profiles, Site U1438. Arrowed values = seawater data at ~6 m below sea surface.

Figure F46. Salinity, chloride, bromide, sodium, potassium, calcium, and magnesium depth profiles, Site U1438. Arrowed values = seawater data at ~6 m below sea surface.

Figure F47. Boron, lithium, silica, manganese, barium, and strontium depth profiles, Site U1438. Arrowed values = seawater data at ~6 m below sea surface.

Figure F48. A. Crystalline precipitates in IW samples acidified for ICP-AES analysis. B. Photomicrograph (XPL). C. XRD pattern in red with predicted peak locations for gypsum in blue. WL = wavelength.

Figure F49. Methane, calcium carbonate, TOC, and TN depth profiles, Site U1438.

Figure F50. Sediment major element depth profiles, Site U1438.

Figure F51. Si/Mg and Al_2O_3 depth profiles for sediments and sills, Site U1438. Solid line represents relative grain size distribution (see **Core descriptions**).

Figure F52. Y vs. Zr for samples from a compilation of global mid-ocean-ridge basalts (Jenner and O'Neill, 2012), Site 1201 (Savov et al., 2005), fore-arc basalts (FAB) from the Mariana fore arc (Reagan et al., 2010), and Unit 1, Site U1438.

Figure F53. Downhole variations in low-field MS in archive-half cores measured with the SHMSL, Site U1438.

Figure F54. Downhole variations in NRM intensity in archive-half cores measured with the SRM, Site U1438.

Figure F55. Low-field magnetic susceptibility and NRM intensity by lithostratigraphic unit based on archive-half core SHMSL and SRM measurements, Site U1438.

Figure F56. NRM Intensity vs. low-field magnetic susceptibility, Site U1438. Variations parallel to the dashed lines reflect variations in the concentration of magnetic phases.

Figure F57. NRM directions in Units I, II, and 1, Site U1438. Top: individual determinations. Bottom: same data represented by Kamb contours. All units show dominance of steep downward directions resulting from a pervasive drilling-induced magnetic overprint. Unit II sediments and Unit 1 basalts also show a preferred clustering of NRM directions biased toward the core *x*-axis, resulting from the radial component of the drilling-induced magnetization (Acton et al., 2002). Produced using Rick Allendinger's Stereonet program v. 8.9.6 (Cardozo and Allmendinger, 2013).

Figure F58. Variation in (left) NRM inclination and (right) inclination after AF demagnetization to 25 mT with low-field magnetic susceptibility for Units I–III, Site U1438.

Figure F59. Examples of AF demagnetization of Unit I archive-half core sections, Hole U1438A. For Figures F59 through F64: solid circles = projection onto the horizontal plane, open circles = projection onto either the vertical X–Z or Y–Z planes.

Figure F60. Examples of AF demagnetization of archive-half core sections showing clear ChRM components following removal of the steeply inclined drilling-induced overprint, Hole U1438B.

Figure F61. Examples of AF demagnetization of archive-half core sections showing clear ChRM components following removal of the steeply inclined drilling-induced overprint, Hole U1438D.

Figure F62. Examples of AF demagnetization of archive-half core sections showing clear reversed polarity magnetizations (following removal of the steeply inclined drilling-induced overprint) that do not reach stable endpoint directions, Hole U1438B.

Figure F63. Examples of AF demagnetization of archive-half core sections showing clear reversed polarity magnetizations (following removal of the steeply inclined drilling-induced overprint) that do not reach stable endpoint directions, Hole U1438D.

Figure F64. Examples of AF demagnetization of archive-half core sections showing dominance of steeply inclined drilling-induced overprints and evidence for hematite-hosted remanences in some samples, Hole U1438E.

Figure F65. Archive-half core section magnetizations after AF demagnetization in a 25 mT applied field, Hole U1438B. Top: data in core reference frame. Bottom: data in geographic reference frame, following application of azimuthal corrections provided by the FlexIT tool. Produced using Rick Allendinger's Stereonet program v. 8.9.6 (Cardozo and Allmendinger, 2013).

Figure F66. Top: Kamb-contoured archive-half core section magnetizations after AF demagnetization at 25 mT (6853 measurement points), showing recovery of antipodal polarity groups after application of FlexIT corrections, Hole U1438B. Bottom: instantaneous geomagnetic field directions calculated from 6853 realizations of the statistical field model TK03.GAD of Tauxe and Kent (2004) for the location of Site U1438. The distribution of these vectors predicts the variability of geomagnetic field directions at the site due to paleosecular variation (PSV). Produced using Rick Allendinger's Stereonet program v. 8.9.6 (Cardozo and Allmendinger, 2013).

Figure F67. Remanence inclinations and declinations, Hole U1438B. Red dashed lines = axial geocentric dipole inclination expected at this site. Declinations have been recovered using azimuthal corrections supplied by the FlexIT tool. Note the clear pattern of geomagnetic field reversals marked by switches in both inclination and declination across reversal boundaries.

Figure F68. Examples of AF and thermal demagnetization of discrete samples, Holes U1438B and U1438D. For Figures F68 and F69: Solid circles = projection onto the horizontal plane, open circles = projection onto the vertical X–Z plane.

Figure F69. Examples of thermal demagnetization of discrete samples, Holes U1438D and U1438E.

Figure F70. AMS data from selected discrete samples, Hole U1438D. Red = maximum principal axes of AMS ellipsoids, blue = minimum principal axes of AMS ellipsoids. Produced using Rick Allendinger's Stereonet program v. 8.9.6 (Cardozo and Allmendinger, 2013).

Figure F71. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438A. For Figures F71 through F75: inclination measured after 25 mT AF demagnetization. Data from within 4.5 cm of section ends have been excluded. Magnetozones are based on inclination data and examination of orthogonal vector plots of demagnetization data and are correlated to the geomagnetic polarity and geological timescales of Gradstein et al. (2012).

Figure F72. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438B, 0–50 mbsf.

Figure F73. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438B, 50–100 mbsf.

Figure F74. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438B, 100–150 mbsf.

Figure F75. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438B, 150–200 mbsf. No usable data were acquired from Core 351-U1438B-25X.

Figure F76. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438D, 200–900 mbsf. PCA piece averages = inclinations of piece-averaged principal components (after filtering out PCA picks with maximum angular deviations > 10°). Magnetozones are based on the inclination data and examination of orthogonal vector plots of demagnetization data, and are correlated to the geomagnetic polarity and geological timescales of Gradstein et al. (2012). For Figures F76 and F77: PCA 40 mT = piece-averaged PCA directions that have the same sign as the piece-averaged 40 mT demagnetization data. PCA 15° = piece-averaged PCA directions that have <15° angular difference with the piece-averaged 25 mT demagnetization data. Green = piece averages with $\alpha_{95} \leq 15°$, red = piece averages with $\alpha_{95} > 15°$, black = pieces with single measurement points, where α_{95} = Fisher (1953) 95% cone of confidence around the mean direction. Remanence data from within 4.5 cm of a piece end have been excluded.

Figure F77. Archive-half core remanent inclination data and magnetostratigraphy, Hole U1438E.

Figure F78. Age-depth model based on correlation between magnetozones and the geomagnetic polarity timescale of Gradstein et al. (2012) (Figures F72–F76), with corresponding calculated linear sedimentation rates, Holes U1438B and U1438D.

Figure F79. Log-log plot of NRM intensity vs. low-field magnetic susceptibility of archive-half core samples of basaltic basement rocks, Hole U1438E. Distribution of values compared to lines of constant Q (Königsberger ratio of remanent to induced magnetization; calculated for field of 32.2 A/m) shows that remanence is substantially greater than induced magnetization in most samples.

Figure F80. Summary of triple combo logs compared with logging and lithostratigraphic units.

Figure F81. Summary of sonic velocities recorded with the FMS-sonic tool string. P-wave sonic velocities are compared with core data. Vertical seismic profile waveforms and one-way arrival time picks (red stars) for Hole U1438F are also shown.

Figure F82. Summary of natural and spectral gamma radiation and correlation with core data. cl = clay, si = silt, vfs-fs = very fine sand–fine sand, ms-vcs = medium sand–very coarse sand.

Figure F83. Physical properties, Holes U1438B (green), U1438D (red), and U1438E (blue). V_P was determined using *x*-direction caliper measurements on working halves. Bulk density (ρ_b), grain density (ρ_g), and porosity (f) were measured on discrete samples with MAD method C. Small gray dots = GRA bulk density. Blue line through the porosity data = simple exponential function with a decay constant of 1200 m. Raw magnetic susceptibilities (κ_{MEAS}) and NGR were measured on whole rounds.

Figure F84. Shear strength (σ_s) of sediments measured by automatic vane shear, Hole U1438B.

Figure F85. P-wave sonic velocities measured on cores, Holes U1438B, U1438D, and U1438E. Hole U1438B: small black dots = whole round measurements every 2.5 cm along the core section. Red dots = *x*-direction caliper measurements on working halves. Blue dots = *z*-direction bayonet measurements on working halves. Hole U1438D: *x*-direction caliper measurements on cores. Hole U1438E: small red dots = *x*-direction caliper measurements on working halves. Green dots = caliper measurements on cubes cut from working halves; value plotted is mean of *x*-, *y*-, and *z*-directions. Error bars = 2σ between the three measurements.

Figure F86. Anisotropy of sonic velocities, Hole U1438E. Left: percent difference in sonic velocities between the *x*- and *y*-directions. The cores are not oriented in the horizontal plane and so the absolute value ($|V_x - V_y|$) is shown. Right: percent difference between the mean horizontal values and the vertical P-wave sonic velocity, expressed as an absolute value.

Figure F87. Temperature, thermal conductivity (k), thermal resistance (Ω) and a Bullard plot from downhole measurements.

Figure F88. Thermal conductivity measured using discrete samples.

Figure F89. NGR, K, Th, and U content and comparison with ash layers described in the cores, Hole U1438D. Dashed lines = ash layer that may have not been described in the cores.

Figure F90. Summary of magnetic flux densities obtained with the Göttingen Borehole Magnetometer and comparison with magnetic susceptibility obtained by logging. IGRF = International Geomagnetic Reference Field.

Figure F91. Examples of dynamically processed FMS images, Hole U1438F.