Figure F1. Site map. Red = Site U1591, yellow = other sites. Inset: location map. See Figure F1 in the Site U1589 chapter (Druitt et al., 2024) for citations for the swath data on which this map is based. KVC = Kolumbo volcanic chain.

Figure F2. Seismic profile across the Christiana Basin along Seismic Line Geomar_P5008. The basin fill has six seismic stratigraphic units (U1–U6), following Preine et al. (2022b). Inset: locations of Site U1591 and Site U1598 in the same basin. Depths in meters.

Figure F3. Lithostratigraphic summary, Site U1591. * = depth and recovery affected by slumped material.

Figure F4. Relative percentages of volcanic, tuffaceous, and nonvolcanic lithologies, Site U1591. Unit I is volcanic rich compared to the nonvolcanic-dominated Unit II. Unit I subunits correspond to smaller scale variations of volcanic vs. nonvolcanic lithologies. * = depth and recovery affected by slumped material.

Figure F5. Average grain size distribution of volcanics, Site U1591. Length of colored bars = relative grain sizes (ash = <2 mm; lapilli = 2–64 mm; mud = <63 µm; sand = 0.063–2 mm), with separate scales shown for volcanic grain size (top) and tuffaceous and nonvolcanic sediments (bottom). Mixed lithologies such as lapilli-ash that have relative grain sizes between two categories are plotted between ticks. Evaporites (green) are not characterized by grain size. * = depth and recovery affected by slumped material.

Figure F6. Core disturbances, Site U1591. A. Mixed sediments. B. Uparching. C. Fall-in. D. Cracking and brecciated core. E. Biscuiting. F. Sediment flowage.

Figure F7. Representative volcanic lithologies from Unit I, Holes U1591A and U1591B. A. Ash layers. B. Ooze with ash. C, D. Lapilli layers. The ooze in D separates two large lapilli packages as shown in Hole U1591B in Figure F3.

Figure F8. Ooze, Hole U1591A. A. Ooze layer (3H-2). B. Ooze with mud (2H-2). C. Ooze with ash (8H-1). D. Tuffaceous mud (8H-2).

Figure F9. Light-colored, highly vesicular, porphyritic pumice from Unit I, Hole U1591A (9H-2, 70–73 cm). A. Vesicle-rich and crystal-poor nature of the pumice (plane-polarized light [PPL]). Phenocrysts of (B) plagioclase (Pl) and (C) clinopyroxene (Cpx), which occur together with Fe-Ti oxide (cross-polarized light [XPL]). Rare apatite occurs as inclusions in pyroxene. The glassy groundmass shows patchy alteration.

Figure F10. Core composites, Holes U1591B and U1591C. A. Cyclic intervals of ooze and organic-rich ooze (sapropelic ooze). B. Small proportion of organic-rich lithologies.

Figure F11. Organic-rich, sapropelic lithologies (extended brown lines), with background lithologies, Holes U1591B and U1591C. Confirmation of sapropelic units requires geochemical analysis of TOC content (see Geochemistry). Gaps in lithologies indicate gaps in recovery, as shown in Figure F3. * = depth and recovery affected by slumped material.

Figure F12. Representative lithologies from Unit II, Holes U1591B and U1591C. A, E. Cyclic repetitions of ooze/mud. B, D, F. Organic-rich (sapropelic) oozes/marl and muds/mudstone with minor ash and tuffaceous mud/sand. C. Sections in Subunit IIb contain volcanic rock cobbles.

Figure F13. Cobbles in Subunit IIb and sandstone in Subunit IIc, Hole U1591C. A, B. Porphyritic extrusive volcanic rock (17R-1, 49–52 cm). (A) PPL; (B) XPL. C, D. Phenocrysts of plagioclase (Pl), amphibole (Am), clinopyroxene (Cpx), and vesicles (V) in the same sample. (C) PPL; (D) XPL. Other phenocrysts in the sample include orthopyroxene (hypersthene), the dominant pyroxene type, and Fe-Ti oxide (Ti-magnetite). Accessory apatite occurs as inclusions in other phases. Glomerocrysts consist of plagioclase, amphibole, and pyroxene. E, F. Immature sandstone (28R-1, 46–48 cm) with abundant grains of plagioclase, benthic foraminifera, and other bioclasts as well as volcanic lithics (L), typically scoria. (E) PPL; (F) XPL.

Figure F14. Representative lithologies from Unit III, Hole U1591C. A, B. Laminated and nodular anhydrite. C. Dolomite with anhydrite veinlets. D. Anhydrite with evidence of plastic deformation and secondary mineralization. E, F. Pumice lapilli within anhydritic mudstone and micrite. A–D: Subunit IIIa; E–F: Subunit IIIb.

Figure F15. Evaporite lithologies from Unit III (XPL), Hole U1591C. A. Sandstone (58R-2, 6–9 cm). B. Sandstone with anhydrite nodules (58R-5, 63–66 cm). C. Laminated anhydrite alternating with micrite (58R-5, 115–118 cm). D. Laminated anhydrite alternating with algal mats and micrite (69R-1, 15–18 cm). E. Fine-grained anhydritic mudstone with crystals including feldspar, quartz, and biotite (71R-1, 90–93 cm). F. Coarse-grained anhydrite characterized by elongated anhydrite and gypsum crystals with interstitial micrite (71R-CC, 20–22 cm).

Figure F16. Exemplary correlations between Holes U1591A and U1591B. A. Volcanic and tuffaceous sediments (ash, tuffaceous ooze, calcareous tuffaceous mud, and lapilli-ash), top to bottom. B. Organic-rich sediments (calcareous tuffaceous mud, organic-rich ooze, and ooze with ash pods). C. Succession of nonvolcanic and volcanic-rich sediments (ooze, tuffaceous ooze, ash, and ooze). The ash layer in A is slightly disturbed, and the calcareous tuffaceous mud is bioturbated (light-colored vertical lenses). The discrete ash layer in C was probably disturbed by drilling; however, it is likely that suspended ash settled over time, leading to a gradational upper boundary.

Figure F17. Exemplary correlations between Holes U1591B and U1591C. A. Succession of ooze, strongly bioturbated organic-rich ooze, to ooze. B. Tentatively correlated gravelly tuffaceous mud to sand with gravel. Drilling disturbance in this sediment interval was strong in Hole U1591B and slight in Hole U1591C. C. Succession of ooze, organic-rich ooze, to ooze (top to bottom) disturbed by drilling especially above the organic-rich interval (Subunit IIa). D. Highly disturbed interval of intermixed ash, tuffaceous muds, and cobble-sized lithics.

Figure F18. Selected XRD spectra of Unit III evaporite lithologies, Hole U1591C. A. Massive anhydrite. B. Anhydrite veinlet. C. Interval dominated by dolomite with minor quartz. D. Interval characterized by a multimineral assemblage of dolomite and quartz with minor calcite and vermiculite. Qtz = quartz, Dol = dolomite, Ver = vermiculite, Cal = calcite.

Figure F19. WRMSL-derived MS data, Holes U1591A and U1591B. The spliced section is shown in the right panel. Note that MS data are on the CCSF-A depth scale and the spliced section is on the CCSF-D depth scale. MS data were clipped at 1600×10^{-5} SI.

Figure F20. Splice for Site U1591 showing MS, NGR, and GRA density, as well as the respective spliced core interval from Holes U1591A–U1591C. cps = counts per second.

Figure F21. CCSF-A versus CSF-A core depths, Holes U1591A and U1591B. Lines fit through the core depths of all holes give an estimate of the affine growth factor. At Site U1591, this is estimated to be approximately 3%.

Figure F22. Dip data, Site U1591.

Figure F23. Box plots of bedding dip distribution in lithostratigraphic units, Site U1591. The minimum (P5), first quartile (P25), median value (P50), third quartile (P75), and maximum (P95) are shown. Only the first outlier that is smaller than P5 and larger than P95 is plotted as a dot. Md = median dip, N = number of samples.

Figure F24. Slumps identified on split core surfaces. A, B. Slump composed of folded sandy laminae/beds in a muddy matrix (398-U1591C-23R-4, 29–97 cm). C. Slump representing block-in-matrix texture containing disturbed/flown muddy clasts within a mud/sand-mixture matrix (398-U1591B-27X-CC, 5–17 cm). D. Slump representing block-in-matrix texture containing pumice and siltstone clasts all within a mud/sand-mixture matrix (398-U1591C-15R-CC, 93–104 cm). E. Base of a slump representing an apparent reverse fault (split arrow; 38R-CC, 37–49 cm). The slip plane is composed of homogenized sand/mud. F. Top of a debris flow deposit (arrow; 398-U1591B-33X-CC, 16–28 cm). Clasts only occur in the uppermost part of the sand layer and indicate reverse grading.

Figure F25. Small faults identified on split core surfaces, Hole U1591C. Arrows indicate the position of the faults and sense of shear direction. A, B. Normal faults identified just below slump layers (A: 40R-3, 33–45 cm; B: 12R-4, 77–88 cm). C, D. Reverse faults (C: 69R-3, 86–98 cm; D: 66R-6, 62–75 cm). Note in C a normal fault also developed.

Figure F26. Sediment-filled veins in Units II and III, Hole U1591C. A–D. Typical occurrences of mud-filled vein structure in Unit II (A: 12R-1, 37–49 cm; B: 26R-4, 104–116 cm; C: 53R-2, 64–74 cm; D: 51R-CC, 0–13 cm). Note in C sand-filled veins (white arrows) apparently developed parallel to the mud-filled veins (black arrows) in the split-core section. E, F. Anhydrite veins developed in Unit III (E: 66R-1, 119–131 cm; F: 67R-2, 2–15 cm). Note small crystal growths (black arrow) along the normal fault (split arrow).

Figure F27. Age-depth plot, Holes U1591A–U1591C. Integrated biochronology and magnetostratigraphy are shown. CN = calcareous nannofossil, MNN = Mediterranean Neogene Nannoplankton, PF = planktonic foraminifer. Hiatuses correspond to periods of significant sediment remobilization. Biohorizons are listed in Tables T6 and T9. * = depth and recovery affected by slumped material.

Figure F28. Calcareous nannofossils. 1. *Emiliania huxleyi* (Lohmann) Hay and Mohler (398-U1591A-3H-CC, 17–20 cm). 2. *Pseudoemiliania lacunosa* (Kamptner) Gartner, (8H-1, 39–41 cm). 3, 4. 398-U1591B-24X-CC, 38–41 cm: (3) *Gephyrocapsa* spp. large form (>5.5 µm); (4) *Gephyrocapsa oceanica* Kamptner. 5. *Sphenolithus abies* Deflandre (398-U1591C-48R-CC, 0–4 cm). 6. *Reticulofenestra pseudoumbilicus* (Gartner) (54R-CC, 42–49 cm). 7. *Cyclicargolithus floridanus* (Roth and Hay) Bukry (60R-1, 3 cm). 8, 9. *Sphenolithus heteromorphus* Deflandre (68R-4, 83–86 cm). 10. *Discoaster brouweri* Tan Sin Hok (23R-CC, 21–24 cm). 11. *Discoaster triradiatus* Tan Sin Hok (398-U1591B-34X-CC, 0–2 cm). 12. *Discoaster pentaradiatus* Tan Sin Hok (398-U1591C-29R-CC, 0–2 cm). 13. *Discoaster surculus* Martini and Bramlette (31R-CC, 19–21 cm). 14. *Discoaster tamalis* Kamptner (32R-CC, 21–23 cm).

Figure F29. Foraminiferal oceanicity and paleowater depth estimates, Site U1591. Blue colors show relationship between oceanicity index and paleowater depth. Observers: AW = Adam Woodhouse, OK = Olga Koukousioura. NA = not applicable. (Continued on next page.)

Figure F30. Biostratigraphic summary, Site U1591. CN = calcareous nannofossil, MNN = Mediterranean Neogene Nannoplankton, PF = planktonic foraminifer. Interpreted oceanicity (Hayward et al., 1999): solid line/red points = interpreted oceanicity, dashed line = extrapolation through barren/unreliable sample data. Interpreted paleowater depths: light blue points/shading = shallower paleowater depth interpretation, dark blue points/shading = deeper paleowater depth interpretation. * = depth and recovery affected by slumped material.

Figure F31. Planktonic foraminifera, Site U1591. A. *Hirsutella margaritae.* B. *Truncorotalia crassaformis* (sinistral) (398-U1591C-20R-CC, 10–15 cm). C. *Truncorotalia crassula* (398-U1591B-32X-CC, 37–40 cm). D. *Globoconella inflata* (1H-CC, 20–23 cm). E. *Globoconella puncticulata*. F. *Globorotalia bononiensis* (398-U1591C-31R-CC, 19–21 cm). G. *Neogloboquadrina atlantica* (sinistral) (398-U1591B-42X-CC, 0–3 cm). H. *Neogloboquadrina pachyderma* (398-U1591A-7H-CC, 24–27 cm). I. *Dentoglobigerina altispira*. J. *Globigerinoides italicus* (398-U1591C-48R-CC, 0–4 cm). K. *Globigerinoides obliquus* (56R-CC, 8–10 cm). L. *Globigerinoides elongatus*. (A, L: 47R-CC, 0-2 cm; E, I: 45R-CC, 23-25 cm).

Figure F32. Planktonic foraminifera, Hole U1591C (unless otherwise specified). A. *Sphaeroidinellopsis seminulina* (56R-CC, 8–10 cm). B. *Sphaeroidinellopsis* sp. (38R-CC, 67–69 cm). C–F. 47R-CC, 0–2 cm: (C) *Globigerina foliata*; (D) *Globoturborotalita apertura*; (E) *Globoturborotalita woodi*; (F) *Globoturborotalita emeisi*. G. *Globoturborotalita nepenthes* (55R-CC, 0–3 cm). H. *Globoturborotalita decoraperta* (45R-CC, 23–25 cm). I. *Beella digitata* (398-U1591A-7H-CC, 24–27 cm).

Figure F33. Benthic foraminifera, Hole U1591C. A, B. *Cibicidoides wuellerstorfi* (8R-CC, 14–16 cm); (A) umbilical view; (B) spiral view. C. *Siphonina reticulata* (13R-CC, 14–16 cm). D. *Bulimina costata* (39R-CC, 0–2 cm). E. *Cibicidoides mundulus* (9R-CC, 9–12 cm).

Figure F34. Histograms of NRM intensity and low-field MS, Site U1591. Data are based on archive-half section SRM measurements and low-field point MS measurements made at the same intervals downhole.

Figure F35. Archive-half section magnetic data, Hole U1591A. Red dashed lines = geocentric axial dipole inclinations expected at this site.

Figure F36. Archive-half section magnetic data, Hole U1591B. Red dashed lines = geocentric axial dipole inclinations expected at this site.

Figure F37. Archive-half section magnetic data, Hole U1591C. Red dashed lines = geocentric axial dipole inclinations expected at this site.

Figure F38. Archive-half section magnetic inclinations, Site U1591. Red dashed lines = geocentric axial dipole inclinations expected at this site.

Figure F39. Archive-half section magnetic inclinations for 480–650 mbsf, Hole U1591C. Data are used to define magnetozones that are correlated to the geomagnetic polarity timescale (GPTS) of Gradstein et al. (2020). Red dashed lines = geocentric axial dipole inclinations expected at this site. Solid/open circles = normal/reversed polarity of discrete samples.

Figure F40. Archive-half section magnetic inclinations for interval 650–820 mbsf, Hole U1591C. Data are used to define magnetozones that are correlated to the geomagnetic polarity timescale (GPTS) of Gradstein et al. (2020). Red dashed lines = geocentric axial dipole inclinations expected at this site. Solid/open circles = normal/reversed polarity of discrete samples.

Figure F41. AF demagnetization of discrete samples (top) and archive-half sections (bottom), Site U1591. The series of reversals shown in Figure F40 are documented. Red/blue arrows = reversed/normal polarity inclinations, solid circles = projection onto horizontal plane, open circles = projection onto vertical plane.

Figure F42. Discrete sample anisotropy of low-field magnetic anisotropy, Hole U1591C. Left: lower hemisphere stereographic equal-area projections of principal anisotropy axes (min = minimum, int = intermediate, max = maximum). Right: shape parameter plotted against corrected anisotropy degree (Jelínek and Kropáček, 1978).

Figure F43. Physical properties, Site U1591. Dots = whole-round measurements, open symbols = discrete sample measurements. Samples with bulk density and *P*-wave velocity greater than the maximum values on the x-axes are plotted in Figure F46. cps = counts per second.

Figure F44. Relationships between lithology and physical properties, Hole U1591A. The top and bottom NGR measurements are removed from each section because the values are affected by edges of sections. White bars on image = void space where IW samples were collected. cps = counts per second.

Figure F45. Relationships between NGR and lithology, Hole U1591B. The top and bottom NGR measurements are removed from each section because the values are affected by edges of sections. White bar on images = void space where IW samples were collected. cps = counts per second.

Figure F46. Discrete physical property measurements, Site U1591. Sediment below shear strength measurements shown was too stiff for measurement. Solid curves = linear least-squares best fits to the data, dashed lines = extrapolations.

Figure F47. ICP-AES analyses of selected volcaniclastic units used to discriminate between potential volcanic sources, Site U1591. A. Total alkali vs. SiO_2 plot with the rock nomenclature of Le Maitre et al. (2002) overlain used for sample naming. Ol = olivine. B. Ba/Y vs. Ba/Zr plot used to correlate samples following Kutterolf et al. (2021).

Figure F48. IW salinity, alkalinity, and pH, Site U1591. Dashed lines = unit boundaries.

Figure F49. IC and ICP-AES concentrations of Br, Cl, B, Na, K, Mg, Ca, and SO_4^{2-} in IW samples, Site U1591. Dashed lines = unit boundaries.

Figure F50. ICP-AES concentrations of Li, Sr, Mn, Ba, and Si in IW samples, Site U1591. Dashed lines = unit boundaries.

Figure F51. TOC and carbonate, Site U1591. Dashed lines = unit boundaries. Sapropel conventions follow Kidd et al. (1978).

Figure F52. Headspace gas analyses of methane, Site U1591. Dashed lines = unit boundaries.