Mining the IODP Database for Relationships Between Lithology and Physical, Chemical, and Magnetic Properties

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Abstract

During each International Ocean Discovery Program (IODP) expedition a vast array of data, typically amounting to hundreds of gigabytes to several terabytes of information, are collected from drill cores. These data include physical, chemical, and magnetic properties and digital images collected continuously or every few centimeters along the cores using automated track systems, as well as a variety of analyses conducted on discrete subsamples taken from the cores. Coring just since the start of Expedition 349 in January 2014 has recovered over 50 km of core, resulting in a very large amount of data, most of which are accessible from the IODP LIMS database. Some of the properties typically measured include P-wave velocity, density, magnetic susceptibility, natural remanent magnetization, natural gamma radiation, and visible spectral reflectance. In addition, the lithology of all cores is described based mainly on visual characteristics of the surface of the split cores, visual examination of smear slides and thin sections, and compositional or mineralogical information derived from geochemical analyses. Our goal in this study is to mine these data for interrelationships that would otherwise be difficult to assess given the way the data are partitioned by specific property within the database. In particular, we extract basic lithologic information from the complex array of descriptive information and then tie that information to all other observations in order to characterize the physical, chemical, and magnetic properties of a myriad of lithologies.

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INTRODUCTION

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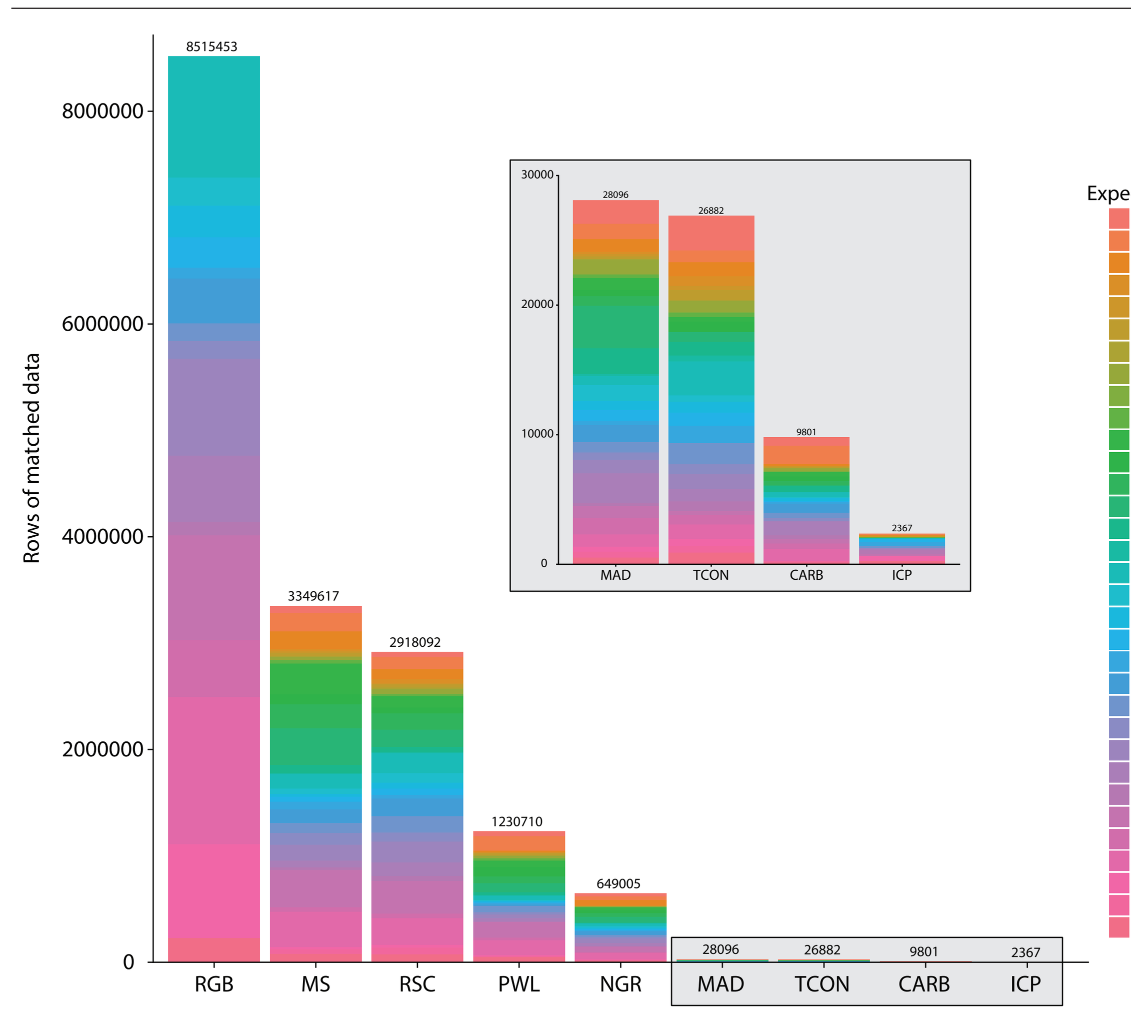
Our goal in this study is to mine these data for interrelationships that would otherwise be difficult to assess given the way the data are partitioned by specific property within the database. In particular, we extract basic lithologic information from the complex array of descriptive information and then tie that information to all other observations in order to characterize the physical, chemical, and magnetic properties of a myriad of lithologies.

EXPEDITIONS

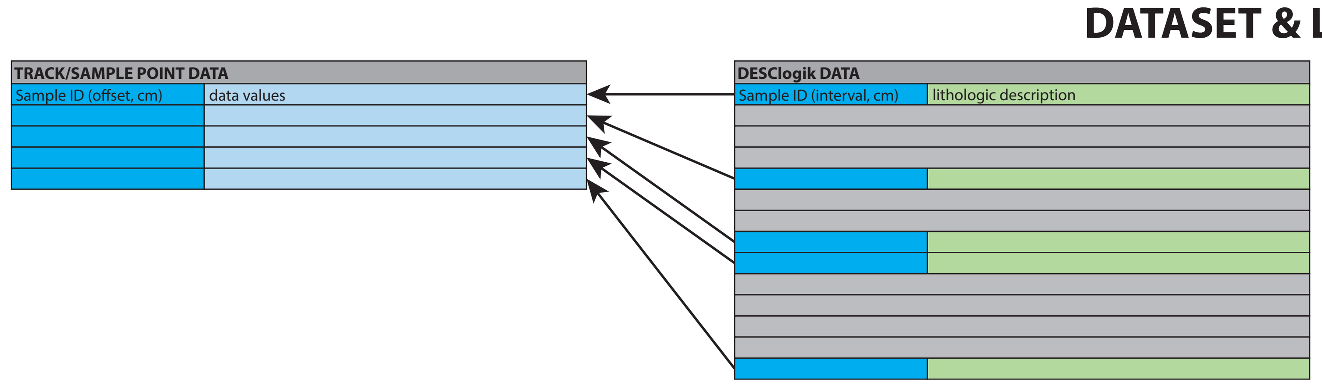
317	Canterbury Basin Sea Level	(Nov 2009–Jan 2010)	349	South China Sea Tectonics	(Jan–Mar 2014)
320	Pacific Equatorial Age Transect	(Mar–May 2009)	350	Izu-Bonin-Mariana Rear Arc	(Mar–May 2014)
323	Bering Sea Paleoceanography	(Jul–Sep 2009)	351	Izu-Bonin-Mariana Arc Origins	(May–Jul 2014)
324	Shatsky Rise Formation	(Sep–Nov 2009)	352	Izu-Bonin-Mariana Forearc	(Jul–Sep 2014)
327	Juan de Fuca Ridge-Flank Hydrogeology	(Jul–Sep 2010)	353	Indian Monsoon Rainfall	(Nov 2014–Jan 2015)
329	South Pacific Gyre Subseafloor Life	(Oct–Dec 2010)	354	Bengal Fan	(Jan–Mar 2015)
330	Louisville Seamount Trail	(Dec 2010–Feb 2011)	355	Arabian Sea Monsoon	(Mar–May 2015)
334	Costa Rica Seismogenesis Project (CRISP-A1)	(Mar–Apr 2011)	356	Indonesian Throughflow	(Jul–Sep 2015)
335	Superfast Spreading Rate Crust 4	(Apr–Jun 2011)	359	Maldives Monsoon and Sea Level	(Sep–Nov 2015)
336	Mid-Atlantic Ridge Microbiology	(Sep–Nov 2011)	360	SW Indian Ridge Lower Crust and Moho	(Nov 2015–Jan 2016)
339	Mediterranean Outflow	(Nov 2011–Jan 2012)	361	South African Climates (Agulhas LGM Density Profile)	(Jan–Mar 2016)
340	Lesser Antilles Volcanism and Landslides	(Mar–Apr 2012)	362	Sumatra Seismogenic Zone	(Aug–Oct 2016)
341	Southern Alaska Margin	(May–Jul 2013)	363	Western Pacific Warm Pool	(Oct–Dec 2016)
342	Paleogene Newfoundland Sediment Drifts	(Jun–Jul 2012)	366	Mariana Convergent Margin & S Chamorro Seamount	(Dec 2016–Feb 2017)
344	Costa Rica Seismogenesis Project (CRISP-A2)	(Oct–Dec 2012)	367	South China Sea Rifted Margin	(Feb–Apr 2017)
345	Hess Deep Plutonic Crust	(Dec 2012–Feb 2013)	368	South China Sea Rifted Margin	(Apr–Jun 2017)
346	Asian Monsoon	(Jul–Sep 2013)			

TRACK & SAMPLE DATASETS



Extent of physical, chemical, and magnetic datasets paired with lithologic descriptions for this study. All data were retrieved from the IODP Laboratory Information Management System (LIMS) [http://web.iodp.tamu.edu/LORE/]. RGB = Red-Green-Blue color from the Section Half Imaging Logger (SHIL). MS = magnetic susceptibility from the Whole-Round Multisensor Logger (WRMSL). RSC = reflectance spectroscopy and colorimetry from the Section Half Multisensor Core Logger (SHMSL). PWL = P-wave logger from WRMSL. NGR = Natural Gamma Radiation from the Natural Gamma Radiation Logger (NGRL). MAD = Moisture and Density from discrete samples. TCON = thermal conductivity measured with the Teka Berlin TK04 probe. CARB = fundamental elemental components (total carbon, hydrogen, nitrogen, and sulfur), inorganic carbon (carbonate), and organic carbon measured on discrete samples. ICP = Inductively-coupled plasma data from discrete samples for a range of major element oxides including $Al2O_3$, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, and TiO_2 and minor elements including Ba, Co, Cr, Cu, Sc, Sr, V, Zn, and Zr.

DATASET & LITHOLOGY PAIRING



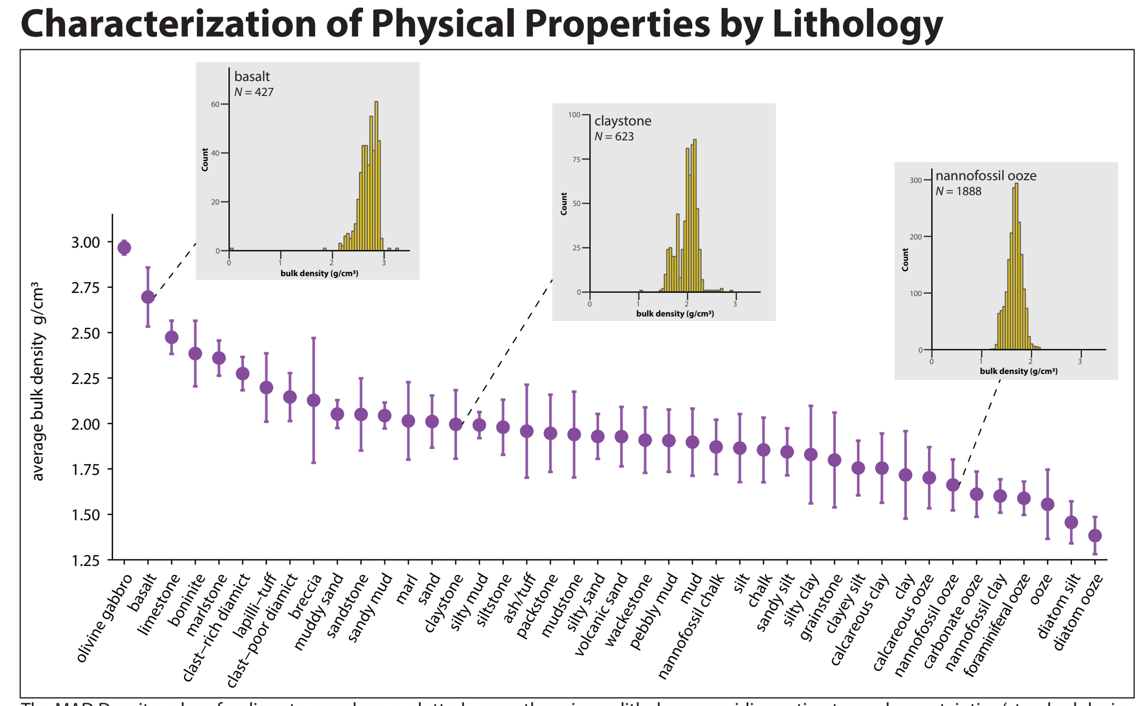
Lithologic descriptions are paired with track data based on the Expedition, Site, Hole, Core Type, Core, Section, and point (track and sample measurements) or interval (cm range) within the section.

The lithologic data are taken from DESClogik workbooks available from LIMS. Descriptive terminology varies amongst the expeditions, but generally lithologies are described with a principal name that may have major modifiers given as prefixes and minor modifiers as suffixes. For sedimentary rocks, the major modifier generally infers a composition that is >25% and minor modifiers are for compositions between 10-25% (Mazzullo and Graham, 1988, Handbook for Shipboard Sedimentologists). Hence, a lithology such as a "nannofossil ooze with diatoms" is an ooze composed of >25% nannofossils and 10-25% diatoms.

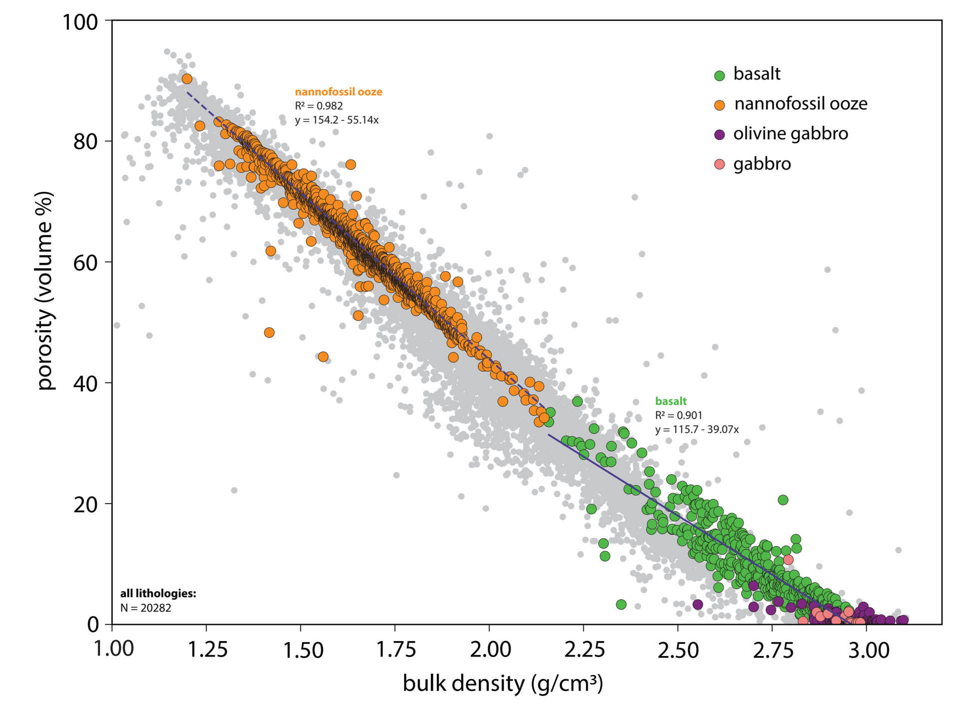
Lithologies across multiple expeditions are merged into three main columns that give the lithology prefix, the principal (or dominant) lithology, and the lithology suffix. While these three columns of lithologic data are used in the analyses shown here, all lithologic description data recorded in the DESClogik workbook tab is paired to the track/sample data. Each file is also paired with pertinent metadata, such as the Latitude, Longitude, and Water Depth.

TRACK/SAMPLE POINT DATA		lithology prefix	lithology	lithology suffix
Sample ID (offset, cm)		ash rich	clay	with diatoms
		NA	sand	NA

Characterization of Physical Properties by Lithology

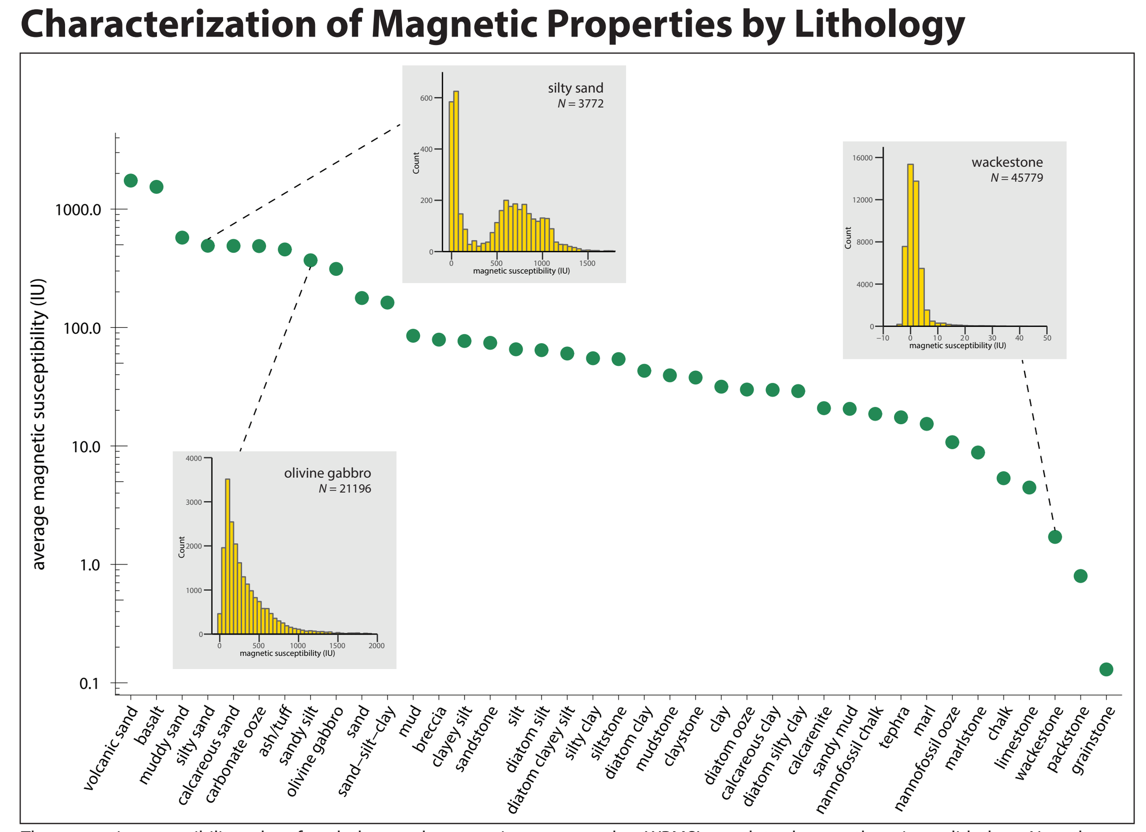


The MAD Density values for discrete samples are plotted versus the primary lithology, providing estimates and uncertainties (standard deviations) for those lithologies that have at least 50 observations. Histograms illustrate results for three lithologies, each with several hundreds of observations.

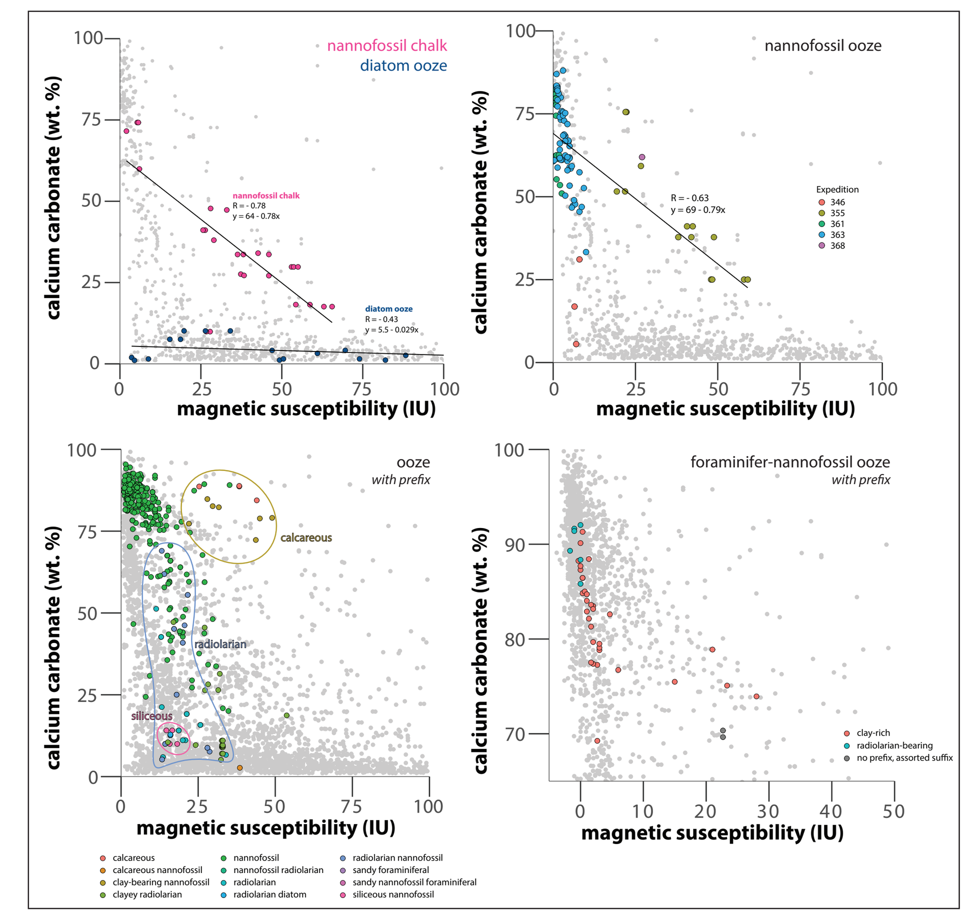


The densities are plotted versus porosity for all data (gray) and for a few selected lithologies (colored dots). Unsurprisingly, the deep crustal rocks (gabbro and olivine gabbro) have little to no porosity and high densities. Upper oceanic crust basalts and overlying sediments have fairly linear relationships between density and porosity.

Characterization of Magnetic Properties by Lithology

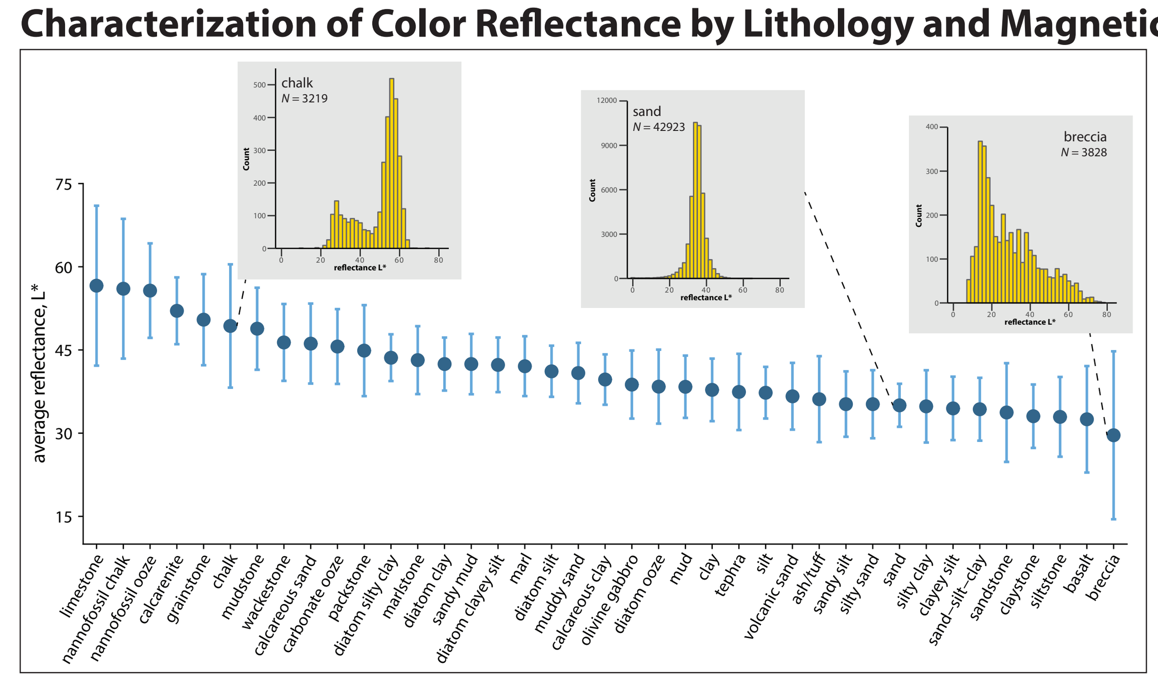


The magnetic susceptibility values for whole-round core sections measured on WRMSL are plotted versus the primary lithology. Note the large number of observations per lithology relative to the MAD density shown above. Uncertainties are not shown because they would be skewed on the log plot and because the distributions of susceptibilities for some lithologies can be multi-modal, as shown in the histograms.

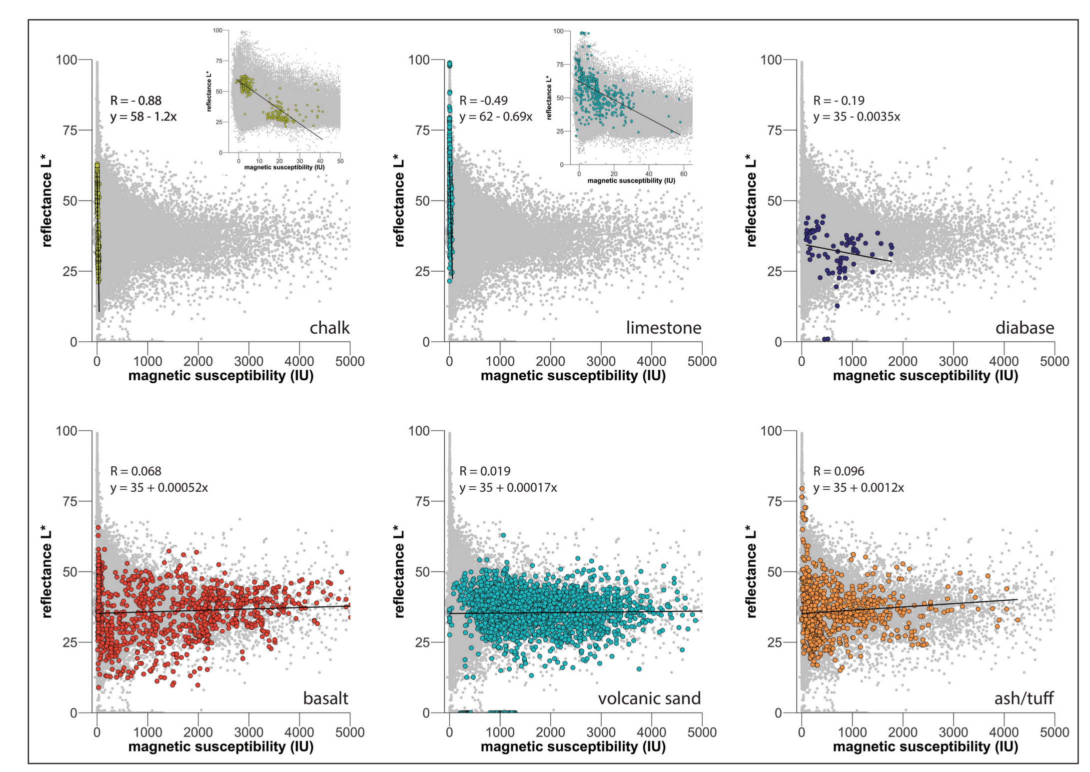


The susceptibilities are plotted versus carbonate content for all data (gray) and for a few selected lithologies (colored dots). Low to negative susceptibilities occur for sedimentary rocks composed of very high to pure carbonate, because $CaCO_3$ is diamagnetic. As more clay is mixed in with the carbonate-rich sediments, susceptibility increases.

Characterization of Color Reflectance by Lithology and Magnetic Susceptibility



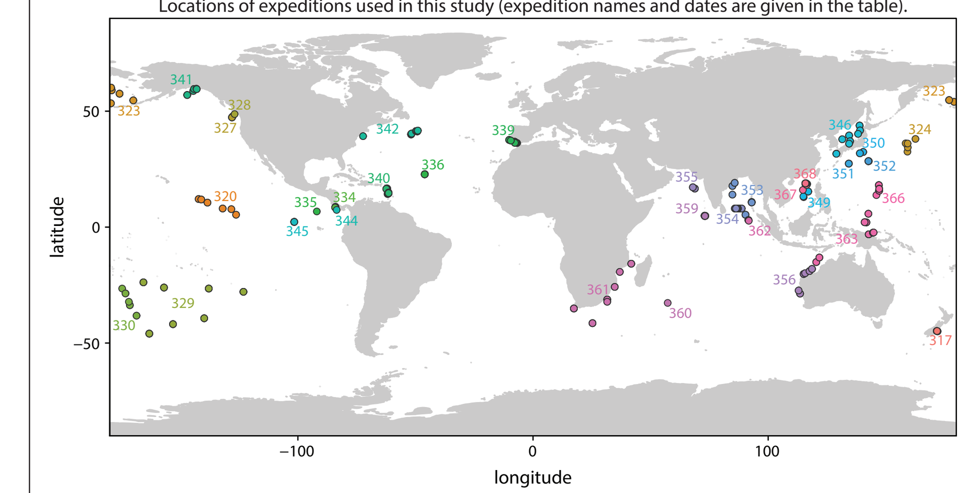
The lightness data (L*, where L*=0 is black and L*=100 is white) collected from the color reflectance (spectrophotometry) measured along the surface of the archive-half core sections using SHMSL are plotted versus the same primary lithologies as shown above for the magnetic susceptibility. The lighter sediments are generally more carbonate-rich, given the very light color of $CaCO_3$. Hence, both L* and magnetic susceptibility can be proxies for carbonate content. As more clay is incorporated into carbonate-rich sediments, they become darker. L* can therefore also be a good proxy for ice volume and temperature in some areas like the northern Atlantic; during glacials more clay is pushed into the oceans by ice sheets producing darker sediment and, during interglacials, sediments are instead composed mainly of the $CaCO_3$ tests of microfossils, and thus have very light color. The alternations of darker and lighter sediments can mimic the variations seen in global oxygen isotope stacks.

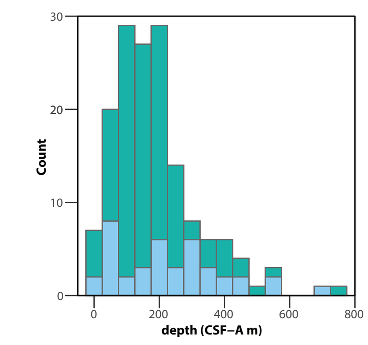


L* is plotted versus magnetic susceptibility for all data (gray) and for a few selected lithologies (colored dots).

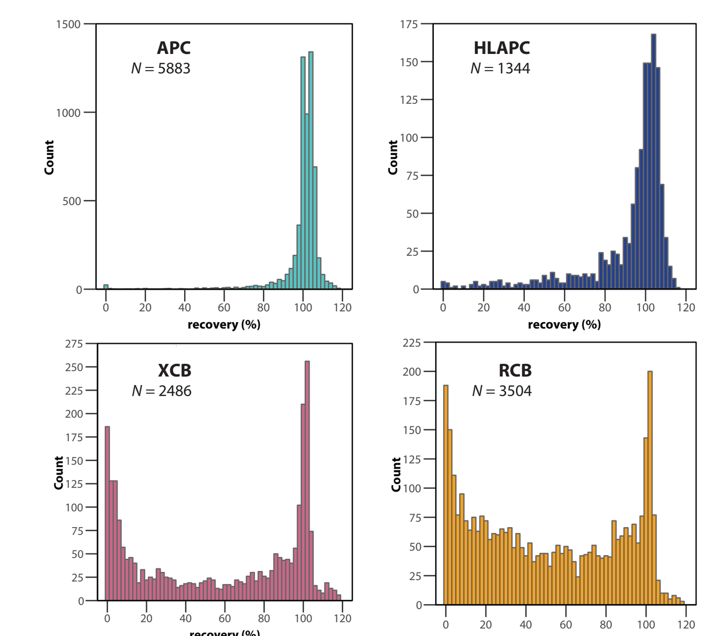
CORING-DRILLING INFORMATION

Locations of expeditions used in this study (expedition names and dates are given in the table).

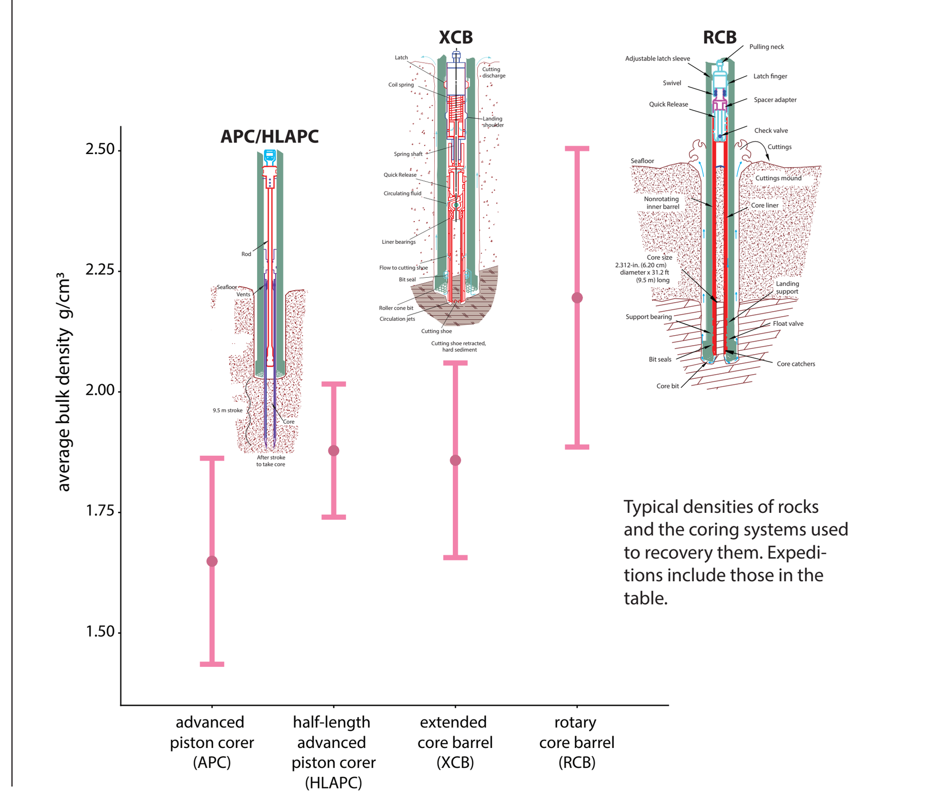




Depth below seafloor (CSF-A m) where use of the APC (green) or HLAPC (blue) is discontinued in favor of another coring system (ex. XCB, RCB). Holes not using APC/HLAPC, or exclusively using APC/HLAPC are not included. Expeditions include those in the table. Bin size = 50. Total counts = 156.



Recovery by coring type. APC = advanced piston corer. HLAPC = half-length advanced piston corer. XCB = extended core barrel. RCB = rotary core barrel. Recovery greater than 120% not included; may be the result of fall-in rather than recovery. Expeditions include only those in the table. A more extensive investigation of the success of the coring systems is being done by H. Evans and B. Clement (2019, in progress).



Typical densities of rocks and the coring systems used to recovery them. Expeditions include those in the table.

SUMMARY

The coupling of track and sample data with lithology provides the means to:

- characterize the physical, magnetic, and chemical properties of common lithologies,
- investigate data connections that may be useful as proxies or for testing hypotheses,
- confirm expected relationships and identify outliers for quality assessment and quality control (QA/QC), with the goal of improving the shipboard instruments and analysis methods.

While we have gathered observations from 33 expeditions from nine track/samples measurement datasets and combined them with lithology, this is only a small part of the ever-growing mountain of observations from *JOIDES Resolution* expeditions. Our goal is to further process and clean the data from the 33 expeditions, add observations from other measurements, and then make the data available (as text files with tabular comma separated values) on an open access database, along with example scripts (e.g., like the R, Python, and Microsoft Power BI scripts used in this study) for analyzing and plotting the data. Methods we are developing will be used to expand the data mining efforts to other expeditions (once out of moratorium) and may eventually be applied for real-time assessment of data as it is collected on future expeditions.

REFERENCES:
All data were retrieved from the IODP Laboratory Information Management System (LIMS) [http://web.iodp.tamu.edu/LORE] for the expeditions listed in the table.
Full citation information for the "Proceedings" volumes for these expeditions are available at http://publications.iodp.org/.
Mazzullo, J., and Graham, A.G. (Eds.), 1988. Handbook for Shipboard Sedimentologists. ODP Technical Note, 8.

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