

Hyperspectral Imaging of Bedrock Core from the Minnesota DNR Drill Core Library: A New Tool for Archival Preservation and Mineral Exploration

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Minnesota’s DNR Drill Core Library

Public archive of > 1M meters of core

- Supports management of state lands and mineral rights
- Promotes mineral exploration and development within the state
- Critical resource for bedrock mapping, mineral potential assessments, and other types of geological research

DNR Corescan Project Goals

- Collect hyperspectral imagery from high-value, high-profile bedrock core archived at the DNR Drill Core Library (DCL).
- Determine how hyperspectral imaging benefits the DCL, Minnesota’s mineral estate, and the state’s mineral industry.
- Support DNR land management decisions and State policy on both minerals diversification and the promotion of mineral exploration and development.
- Leverage Corescan’s hyperspectral core imaging system to answer important local and regional geological questions.

Corescan

Hyperspectral Imagery of Bedrock Core

- Collection, processing and interpretation of co-acquired photography, hyperspectral and laser profiling data
- Expert mineralogical identification and texture mapping
- On-line data access and data management through Coreshed’s virtual drill core library

Drill Core and Focus Area Selection

- DNR geologists selected project core from thirty-two (32) drill holes located within five (5) Focus Areas in Northern and Central Minnesota. These Focus Areas host distinct mineral deposit types and high mineral potential.
- Focus Area and core selection played to the technique’s strengths, and its ability to answer key geological questions that further our understanding of Minnesota’s mineral estate.
- Hyperspectral imaging is a non-destructive analytical technique that supports the archival preservation of limited core material.

Data Collection

Hyperspectral imagery was collected from 4,862 meters of drill core over a five week-long period in Jan-Feb, 2019. Production rates required twelve-hour work days and seven-day work weeks. More than 16,000 boxes of core were pulled from archival storage, cleaned and staged for scanning, scanned, and then returned to storage.

Prep time varied significantly based on the condition of the core and core boxes. Plans to scan some cores were dropped when prep times would have been inordinately long. This resulted in the last-minute addition of the Animikie SEDEX Focus Area and its six cores to the project.

Focus Area	Target	Number of cores	Total meters
Mesabi Range (Biwabik Iron Formation)	Iron	6	1510
International Falls Greenstone (Seine Group)	Gold	12	1964
Cuyuna Range (Emily District)	Manganese	5	354
Duluth Complex (Longnose Titanium Deposit)	Vanadium	3	621
Animikie Basin (Southern Edge)	SEDEX	6	413
		32	4,862

Data Processing and Interpretation

Spectral and radiometric calibrations are performed using NIST traceable rare earth and Spectralon® reflectance standards prior to and after scanning a tray. Hyperspectral image data sets are imported into proprietary Corescan spectral analyses software (Chameleon™) and analysed with a suite of project specific algorithms which aim to both identify and spatially map mineralogy. Using a combination of absorption feature extraction, spectral ratio and spectral match algorithms, the extracted Corescan spectra are compared against validated spectral libraries such as the USGS SpecLib07 (Kokaly et al., 2017) and the Corescan internal library; this process populates a specific project spectral library that covers the different mineralogy within each deposit, and allows the generation of visual abundance images and mineral classification maps.

Early results: International Falls-Greenstone Gold

The Seine Group of greenschist-facies, metasedimentary and metavolcanic rocks sits at the contact between the Wabigoon and Quetico Subprovinces of the Archean Superior Province (Jirsa et al., 2014). Gold exploration in the region included an active period of drilling in the late 1980’s. Frey (2012) re-logged and re-sampled several of the DCL-archived Seine Group cores, and identified alteration patterns and features favorable for gold mineralization, including greater abundances of porphyroblastic and vein tourmaline. Hyperspectral imaging of twelve archived DCL cores from the area extends Frey’s tourmaline observations to drill cores that (due to active exploration) were not available at the time of his study. There is a positive correlation between gold concentrations and hyperspectral mineral identification of under-recognized tourmaline.

Early results: Biwabik Iron Formation

Complete or near complete transects of the Biwabik Iron Formation (BIF) were imaged in six Mesabi Range drill cores (LWD99-1, LWD99-2, MDDP-2, -5, -7, and -8). Hyperspectral imaging of core from LWD99-2 is able to differentiate microplaty hematite banding from more martite- and magnetite-rich bands. Variation in the composition of chlorite (magnesium to iron-rich) and carbonate (calcium to iron-rich) are also recognized within the same core based on absorption features.

Average albedo in the visible spectral range (448-740nm) highlights variation within the heavily sampled contact between the BIF and overlying Virginia Formation, where Addison et al. (2005) identified an ~25 to ~58cm thick ejecta layer associated with the 1850Ma Sudbury impact event. Illite/white mica is recognized based on absorption features within an ~ 2.6m interval of LWD99-2 core at the transition from BIF to Virginia Formation. Within this occurrence interval, a much smaller ~ 38cm interval with ammonium-rich illite/white mica (feature around 2010nm, Canet et al. (2015)) is recognized in a thin layer of cherty carbonate. The occurrence of relatively rare ammonium-rich phyllosilicate as a secondary mineral at this high-profile contact, if confirmed, would be significant.

First-time Public Access to Coreshed Data

Hyperspectral Imaging is a data-intensive process that generates 1.6Gb of raw data for every meter of scanned core. Effective interpretation of thousands of meters of core imagery would be impossible without software support. Corescan has therefore developed a proprietary online virtual drill core library (Coreshed) that stores, manages, and supports the visualization of their client’s hyperspectral data sets.

The DNR Corescan Project will, for the first time, give the general public log-in access to data that is archived on the Coreshed on-line virtual core library.

Next Steps

- Corescan completes the processing and interpretation of project data from the five focus areas, uploads results to Coreshed, and delivers finalized results to DNR (Spring, 2019).
- DNR combines the Corescan results with supporting maps, metadata and other digital documents, releases the integrated data set to the public, and provides log-in access to Coreshed (Summer, 2019).
- Collect and interpret independent core data (e.g. thin-section petrography, EMP and/or XRD analyses) required to validate/assess selected hyperspectral interpretations.
- Publish peer-reviewed research papers and/or open-file reports (as appropriate) for each of the Focus Areas, as well as a report that provides an overall project assessment.

Acknowledgements and Cited References

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Mineral Abundance Logs

Corescan’s spectral datasets can be used for mineral abundance estimates down the length of a drill core. The number of pixels that identify a specific mineral of interest is divided by the total number of pixels within a set interval to get an abundance percentage. This is a semi-quantitative estimate, since hyperspectral imaging only captures data from an ~5µm surface layer on one side of a core fragment. It also differs from quantitative modal analysis in that the summed abundance percentages are invariably greater than 100% (since pixels can be linked to more than one mineral when the pixel covers grain boundaries, or when the rock is fine-grained).

Mineral abundances can either be calculated for uniform core intervals (e.g. 0.5 ft), or for client-identified irregular intervals. The later can be used to link mineral abundance estimates to stratigraphic units or assayed intervals.

Integration of External Data Sets

Corescan can import other datasets associated with scanned core into its Coreshed viewing platform, with full synchronization of that dataset’s depth markers. Visual co-registration allows direct comparisons of this external data with Corescan’s high resolution RGB photography, hyperspectral imagery, and mineral abundance logs.

The figure below illustrates the strength of this type of data visualization. Modal abundance logs for International Falls-Greenstone Gold core ND-1 were calculated at 0.5ft increments for the full core length, with the relative abundances of chlorite, carbonate, epidote, prehnite and tourmaline plotted in bar charts as a function of depth. Historical gold assay results were imported and plotted on the far right, with the width of each bar corresponding to sample interval. The combined plot shows a link between tourmaline occurrence and gold content.



Stacked-Section Data Visualization

Corescan’s online viewing platform can display results either as digitally reconstructed vertical boreholes, or in a “stacked-section” format that displays individual core boxes vertically. Stacked-section views allow users to analyze longer intervals of core within a single image.

At right: Stacked-section views of a 5.5m interval of LWD99-2 at the base of the Virginia Formation, including a 4.5m interval of (now) quarter-core that was sampled by Bill Addison for research on the Sudbury ejecta layer.

Mineral Keys

Mineral classification maps display the occurrence of all detected minerals in a single image map. Minerals that lack VNIR/SWIR absorption features are mapped as “aspectral”. A combination of minerals can be mapped as a single unit when the observed spectra can’t be further resolved.

Mineral keys identify the colours used to map each mineral. Since a single 500µm pixel may contain multiple minerals, each mineral key is stacked based on a ranking system that determines which minerals are plotted on mineral classification maps. Mineral map colours and class map rankings can be adjusted based on desired analysis and visualization goals.

Preliminary Mineral Key
International Falls-Greenstone Gold

Colour	Mineral Name
Orange	Tourmaline
Red	Garnet
Yellow	Green Mica
Light Green	Sulfide
Dark Green	Talc
Light Blue	Epidote
Dark Blue	Prehnite
Light Purple	Zoisite
Dark Purple	Fe-Carbonate
Light Cyan	Carbonate
Dark Cyan	Amphibole
Light Green	Actinolite
Dark Green	Sepiolite
Light Blue	Hydrous silica
Dark Blue	Montmorillonite
Light Purple	White Mica + Chlorite
Dark Purple	White Mica + Aspectral
Light Cyan	Gypsum
Dark Cyan	White mica
Light Green	Chlorite
Dark Green	Amphibole-Fe
Light Blue	Pyroxene
Dark Blue	Aspectral 2
Light Purple	Aspectral
Dark Purple	Aspectral-Fe

Class Map Ranking

Preliminary Mineral Key
Biwabik Iron Formation – Mesabi Range

Mineral Name	Colour
Hematite + Quartz	Orange
Goethite	Red
Montmorillonite	Yellow
Chert + Illite/White Mica*	Light Green
NH4-Illite/White Mica	Dark Green
Illite/White Mica	Light Blue
Fe-Carbonate	Dark Blue
Quartz	Light Cyan
Jasper + Fe-Carbonate	Dark Cyan
Jasper	Light Purple
Chert + Fe-Carbonate	Dark Purple
Microplaty Hematite	Light Cyan
Martite	Dark Cyan
Fe-Oxide Mixture	Light Green
Fe-Talc	Dark Green
Talc	Light Blue
Greenalite	Dark Blue
Minnesotalite	Light Purple
Stilpnomelane	Dark Purple
Fe-Chlorite	Light Cyan
Chlorite	Dark Cyan
Carbonate + Silicate	Light Green
Chert + Carbonate*	Dark Green
Carbonate	Light Blue
Magnetite Mixture	Dark Blue
Magnetite	Light Cyan
Chert Mixture	Dark Cyan
Chert	Light Purple
Chert + Slate	Dark Purple
Slate	Light Cyan

* Only displayed in the class map

Class Map Ranking

Preliminary Mineral Key
Cuyuna Range Manganese

Colour	Mineral Name
Green	Chlorite
Orange	Carbonate
Yellow	Opaline Silica
Light Green	Goethite
Dark Green	Montmorillonite
Light Blue	Nontonite
Dark Blue	White Mica
Light Purple	Quartz
Dark Purple	Kaolinite
Light Cyan	Chert
Dark Cyan	Jasper
Light Green	Microplaty Hematite
Dark Green	Hematite
Light Blue	Magnetite
Dark Blue	Sed (Type 1)
Light Purple	Dark Sed (Type 2)

Class Map Ranking

Preliminary Mineral Key
Virginia Formation

Mineral Name	Colour
Slate	Orange
Slate Mixture	Red
Carbonate	Yellow
Fe-Carbonate	Light Green
Carbonate + Silicate	Dark Green
Quartz	Light Blue
Illite/White Mica	Dark Blue
NH4-Illite/White Mica	Light Cyan
Fe-Chlorite	Dark Cyan
Chlorite	Light Purple
Chert Mixture	Dark Purple
Chert + Carbonate	Light Cyan
Chert + Slate	Dark Cyan
Chert	Light Green
Hematite + Quartz	Dark Green
Goethite	Light Blue
Montmorillonite	Dark Blue
Chert + Illite/White Mica	Light Purple
Jasper + Fe-Carbonate	Dark Purple
Jasper	Light Cyan
Chert + Fe-Carbonate	Dark Cyan
Microplaty Hematite	Light Green
Martite	Dark Green
Fe-Oxide Mixture	Light Blue
Fe-Talc	Dark Blue
Talc	Light Purple
Greenalite	Dark Purple
Minnesotalite	Light Cyan
Stilpnomelane	Dark Cyan
Magnetite Mixture	Light Green
Magnetite	Dark Green

Preliminary Mineral Key
Pogekama Quartzite

Mineral Name	Colour
Quartz	Orange
Hematite + Quartz	Red
Illite/White Mica	Yellow
NH4-Illite/White Mica	Light Green
Chert + Illite/White Mica	Dark Green
Fe-Chlorite	Light Blue
Montmorillonite	Dark Blue
Slate Mixture	Light Cyan
Slate	Dark Cyan
Carbonate	Light Purple
Fe-Carbonate	Dark Purple
Chert + Slate	Light Cyan
Chert + Carbonate	Dark Cyan
Carbonate + Silicate	Light Green
Goethite	Dark Green
Chert Mixture	Light Blue
Jasper + Fe-Carbonate	Dark Blue
Jasper	Light Purple
Chert + Fe-Carbonate	Dark Purple
Microplaty Hematite	Light Cyan
Martite	Dark Cyan
Fe-Oxide Mixture	Light Green
Fe-Talc	Dark Green
Talc	Light Blue
Greenalite	Dark Blue
Minnesotalite	Light Purple
Stilpnomelane	Dark Purple
Magnetite Mixture	Light Cyan
Magnetite	Dark Green