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

ELSENHEIMER, Don[1](donald.elsenheimer@state.mn.us), DEYELL-WURST, Cari[2], and FONTENEAU, Lionel C.[3]

[1]Minnesota Department of Natural Resources, 500 Lafayette Rd, St. Paul, MN 55155 USA; [2]Corescan Pty Ltd, 22033 Boul Gouin Ouest, Montreal, QC, CANADA;[3]Corescan Pty Ltd, 1/127 Grandstand Road, Ascot WA 6104, AUSTRALIA

Minnesota's DNR Drill Core Library

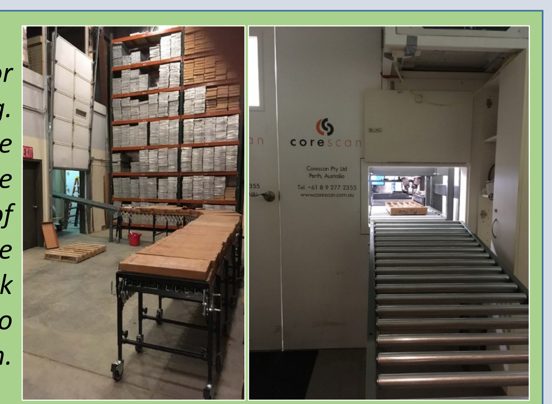
Public archive housing over one million meters of core

- Supports management of state lands and mineral rights
- Promotes mineral exploration and development within the state
- Critical resource for bedrock mapping and 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.

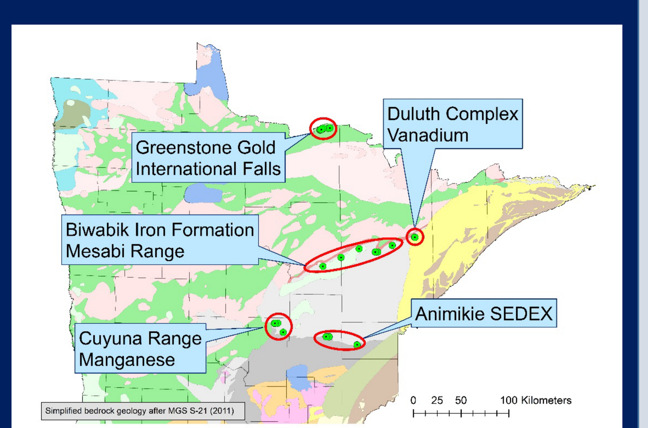
Production line for core box scanning. Boxes were fed one at a time into the lab. A 10ft box of NQ drill core (47.6mm dia.) took 12-13 minutes to scan.



Drill core was either scanned within its storage box or transferred to wood trays as shown. This tray also shows how different types of material was staged for scans.

Drill Core and Focus Area Selection

DNR geologists selected drill 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.

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	4862

Data Collection

Scans were taken of 4,862 meters of core over five 7-day work weeks in Jan-Feb, 2019. Over 1,600 boxes were pulled, cleaned, staged, scanned, and reshelved.

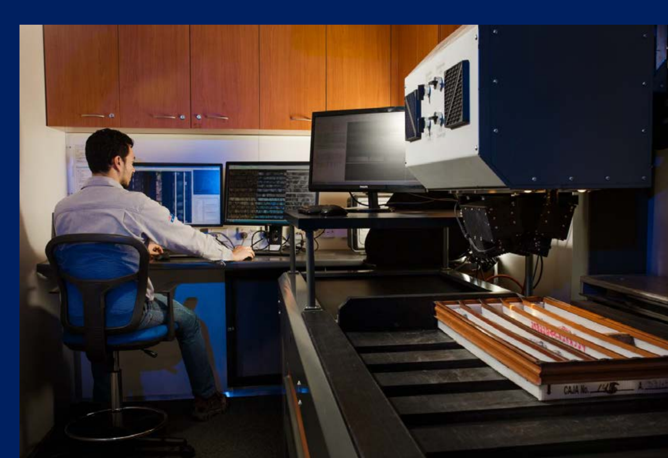
The Animikie SEDEX Focus Area and its six cores were added to the project after preparation of some other selected core proved time-prohibitive.

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 management through Coreshed's virtual drill core library
- Non-destructive analytical technique supports the archival preservation of core.

Corescan's Hyperspectral Core Imager 3

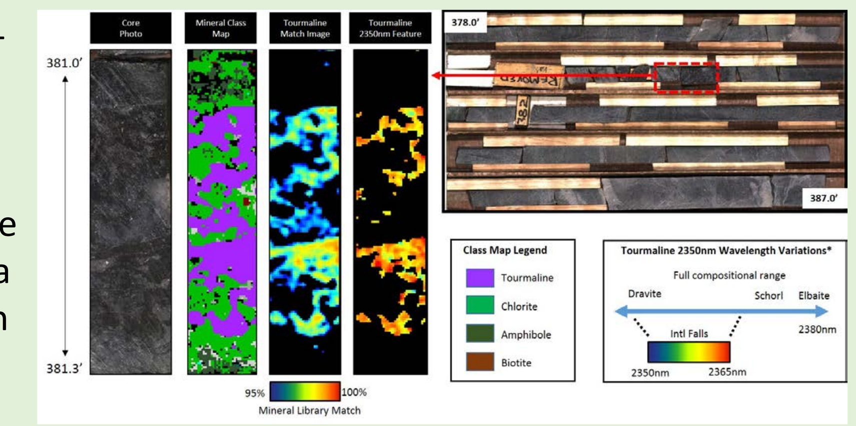
Corescan's HCI-3 hyperspectral core imaging system (Martini et al., 2017) integrates both Visible Near Infrared (VNIR) and Shortwave Infrared (SWIR) reflectance spectroscopy with high-resolution photography (50 mm) and 3-d laser profiling (20 nm resolution) to identify minerals, estimate mineral abundances and create textural images at 500 mm resolution. Corescan operates these systems in both fixed-location bureaus and mobile labs that are housed within shipping containers that can be deployed across the globe for on-site scanning services.



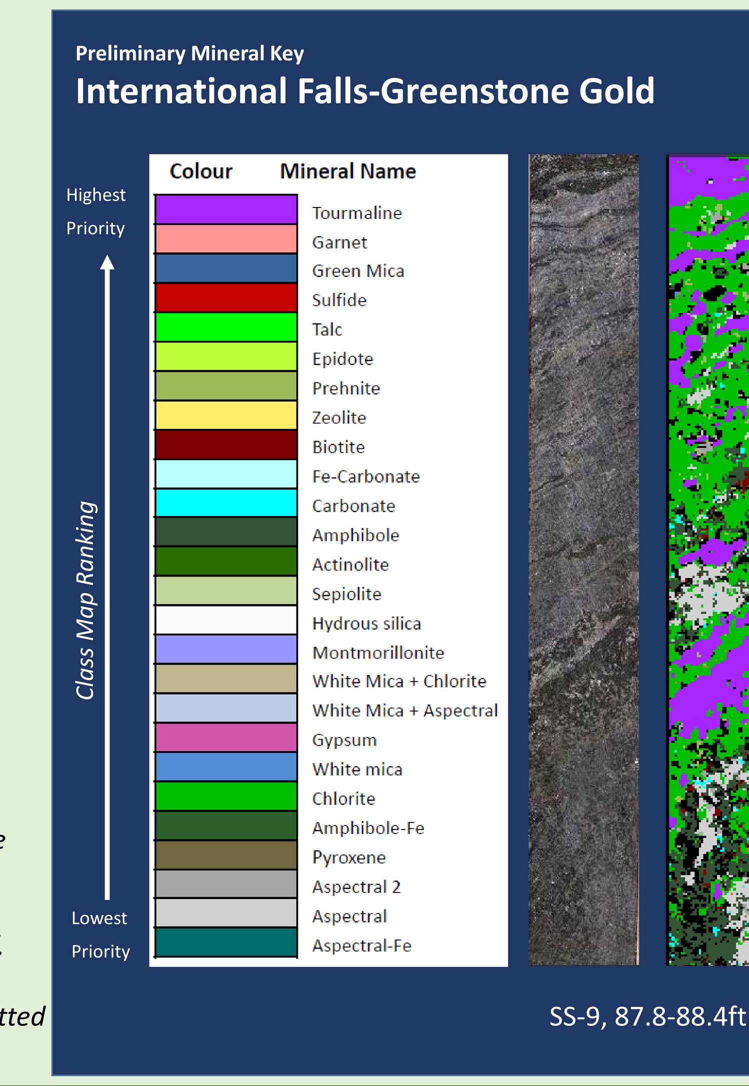
Imaging devices in the Corescan mobile lab include a digital RGB camera (50mm spatial resolution), a 3D Core Surface Profiler for geotechnical logging (~20mm vertical resolution), and VNIR, SWIR-A, and SWIR-B Spectrometers (~4mm spectral resolution)

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 porphyoblastic 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.



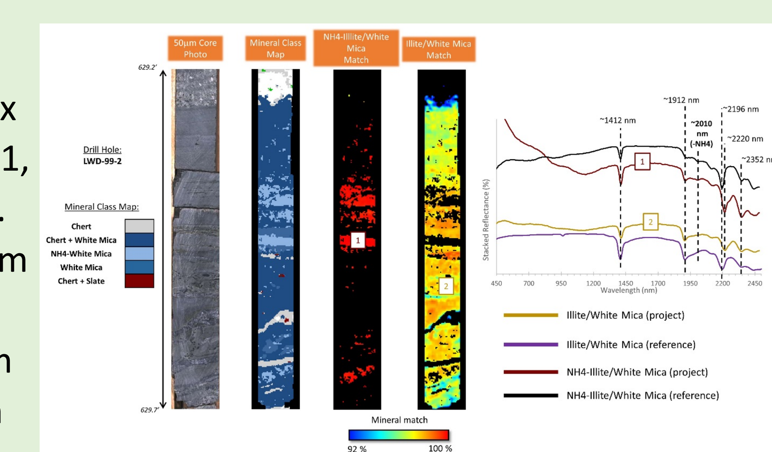
above: Hyperspectral imaging of tourmaline within an 8cm-long section of quarter-core from DDH TC35-1. This section is within a larger 4 foot (1.22m) core interval that assayed at 4020ppb Au. Variations in the 2350nm feature position (Bierwirth, 2008) suggest compositions within the dravite-schorl series.



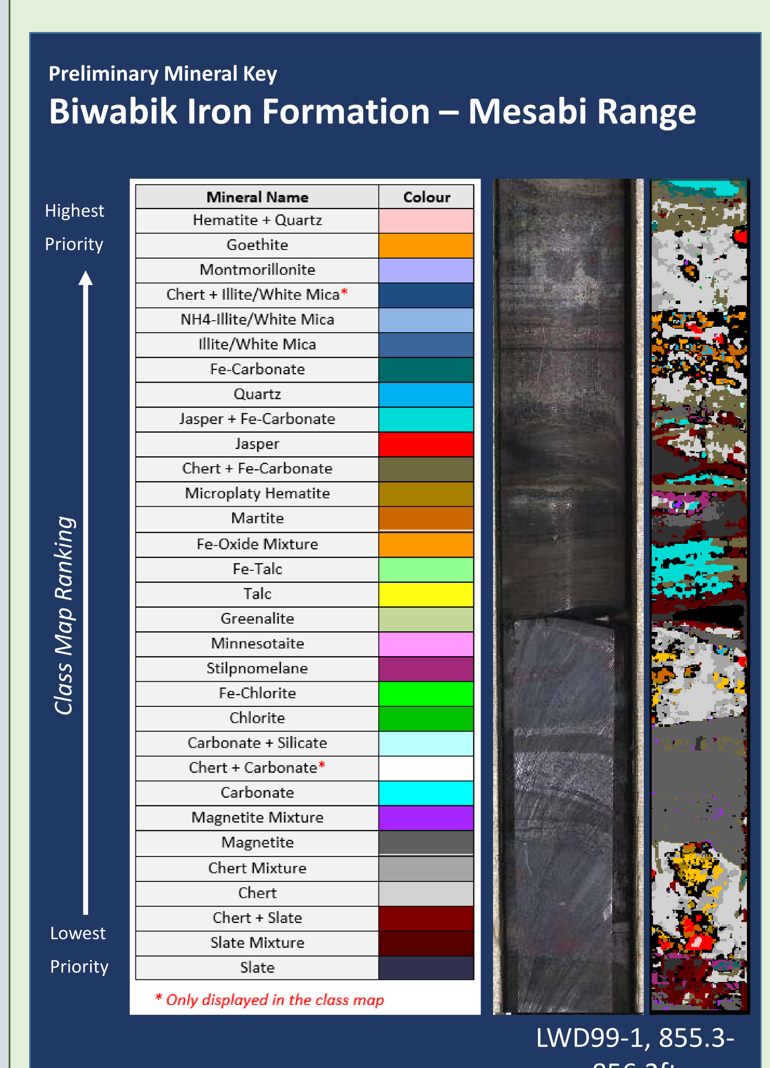
at right: Mineral classification maps display the occurrence of all detected minerals in a single image map. Minerals that lack VNIR/SWIR absorption features are mapped as "aspectral". Each mineral key is stacked based on a ranking system that determines which minerals are plotted on mineral classification maps.

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.



above: Illite/white mica and NH4-illite/white mica occurrences at the contact between Biwabik Iron Formation and Virginia Formation, based on spectral reflectance data below left: Preliminary BIF mineral key



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.

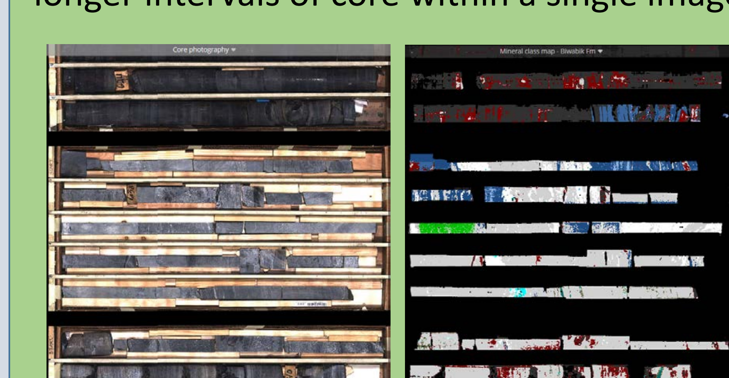
Data Processing and Interpretation

Spectral and radiometric calibrations are performed using NIST traceable rare earth and Spectralon® reflectance standards before and after scanning a tray. Hyperspectral image data are imported into Corescan spectral analyses software (Chameleon™) and analysed with a suite of project specific algorithms to 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.

Stacked-Section Data Visualization

Corescan's online viewing platform can display results 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.



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.

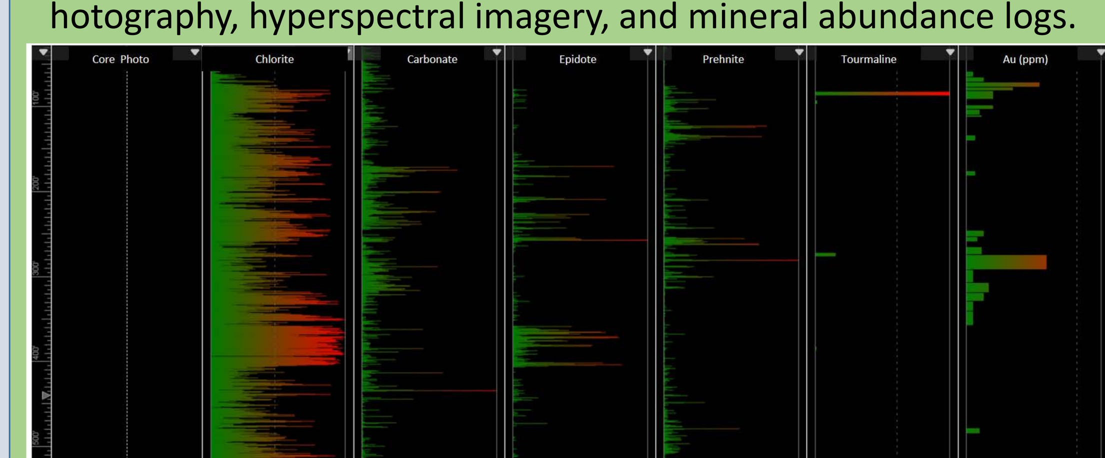
Mineral Abundance Logs

orescan's spectral datasets can be used for mineral abundance stimates down the length of a drill core. Abundance percentages for given mineral are calculated by proportion of pixels in an interval, nd can total over 100% when pixels are linked to more than one mineral in fine-grained rock or on edge pixels

Mineral abundances can be calculated for uniform intervals (e.g. 0.5 t), or for client-identified intervals useful for linking abundance esults to stratigraphic units or assayed intervals.

Integration of External Data Sets

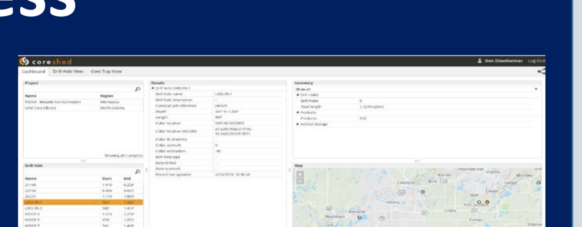
orescan can import datasets associated with scanned core. Visual o-registration allows direct comparisons with Corescan's RGB hotography, hyperspectral imagery, and mineral abundance logs.



First-time Public Access to Coreshed Data

Hyperspectral Imaging generates 1.6Gb of raw data for every meter of scanned core. Effective interpretation of core imagery would be impossible without software support. Corescan developed a virtual drill core library (Coreshed) that supports visualization of hyperspectral data sets.

The DNR Corescan Project is the first to provide public access to Coreshed data.



Coreshed's digital dashboard

Coreshed image of a box of core from the Sudbury ejecta layer overlain by interpreted mineral map.

Next Steps

- Interpret: Corescan completes processing and interpretation and delivers results to DNR and Coreshed *(Spring, 2019)*.
- Access: DNR adds existing maps, metadata, and other information to Corescan results, and shares online and in Coreshed *(Summer, 2019)*.
- Validate: Collect and interpret independent core data required to validate/assess selected hyperspectral interpretations.
- Publication: All results to be published in research papers for each Focus Area and an overall project assessment.

Acknowledgements and Cited References

his project was funded by the MN Dept of Natural esources and the MN Dept of Iron Range Resources & ehabilitation. We would like to thank Heather Arends nd Brigette Martini for the hard work they put into making this collaboration possible. Scanning 16,000+ oxes of drill core was a significant undertaking that ouldn't have been completed without the sweat, ersistence, and sacrificed weekends of Nick Niemi, oyle Birdsall, Doug Rosneau, Cheyanne Dusek, Andrea eed, Glenn Melchert, David Dahl, Thomas Lee, Corrie oyd and others at the DNR Hibbing Office.

Addison W.D., Brumpton G.R., Vallini D.A., McNaughton N.J., Davis D.W., Kissin S.A., Fralick P.W., and Hammond A.L. (2005) Discovery of distal ejecta from the 1850 Ma Sudbury impact event. Geology 33:193-196.

Bierwirth, P.N. (2008) Laboratory and imaging spectroscopy of tourmaline - a tool for mineral exploration. 14th Australasian Remote Sensing and Photogrammetry Conference, Darwin.

Canet C., Hernández-Cruz B., Jiménez-Franco A., Pi T., Peláez B., Villanueva-Estrada R.E., Alfonso P., González-Partida E., Salinas S. (2015) Combining ammonium mapping and short-wave infrared (SWIR) reflectance spectroscopy to constrain a model of hydrothermal alteration for the Acoculco geothermal zone, Eastern Mexico. Geothermics 53:154-65.

Frey B.A. (2012) International Falls Drill Core Descriptions and Chemistry, Koochiching County, Minnesota. Project 378 Open-File Report, Minnesota Department of Natural Resources, Division of Lands and Minerals, 39p.

Kokaly, R.F., R.N. Clark, G.A. Swayze, K.E. Livo, T.M. Hoefen, N.C. Pearson, R.A. Wise, W.M. Benzel, H.A. Lowers, R.L. Driscoll, A.J. Klein (2017) USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61p.

Jirsa M.A., Boerboom T.J., and Chandler V.W. (2014) M-197 Bedrock Geology of the International Falls and LittleFork 30'x60' Quadrangles, northern Minnesota. Minnesota Geological Survey, Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/166157.

Martini B.A., Harris A.C., Carey R., Goodey N., Honey F., and Tufilli N. (2017) Automated Hyperspectral Core Imaging – A Revolutionary New Tool for Exploration, Mining and Research. in "Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration" edited by V. Tschirhart V. and M.D. Thomas, p. 911-922.

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

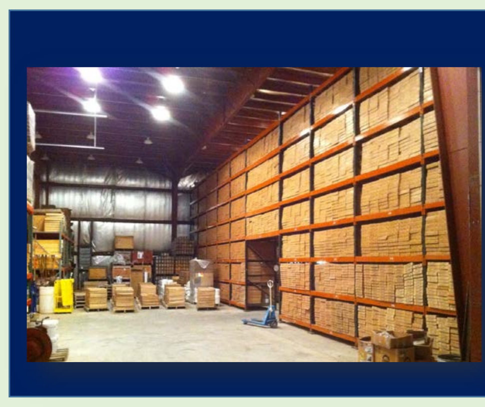
ELSENHEIMER, Don[1](donald.elsenheimer@state.mn.us), DEYELL-WURST, Cari[2], and FONTENEAU, Lionel C.[3]

[1]Minnesota Department of Natural Resources, 500 Lafayette Rd, St. Paul, MN 55155 USA; [2]Corescan Pty Ltd, 22033 Boul Gouin Ouest, Montreal, QC, CANADA; [3]Corescan Pty Ltd, 1/127 Grandstand Road, Ascot WA 6104, AUSTRALIA

DEPARTMENT OF NATURAL RESOURCES

corescan

Minnesota's DNR Drill Core Library



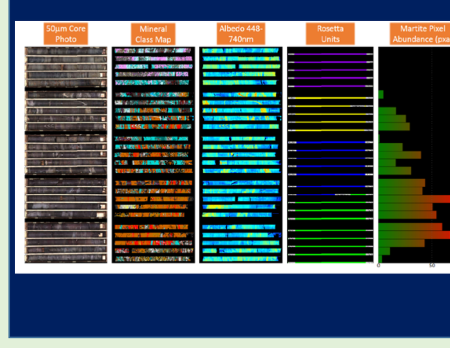
Public archive of > 1M meters of core

- 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

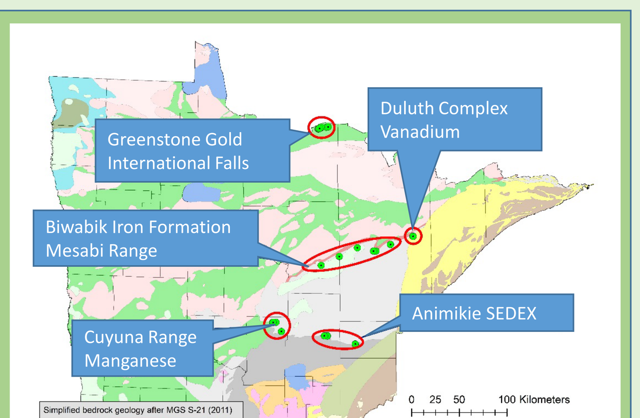


Hyperspectral Imagery of Bedrock Core

- 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

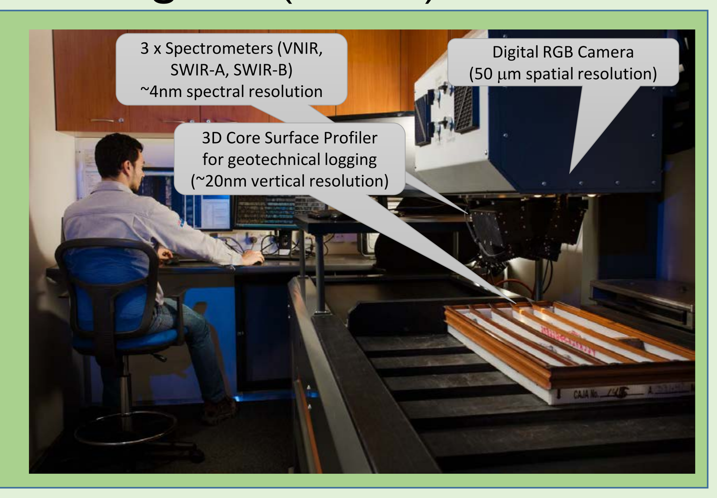
Drill Core and Focus Area Selection

- 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.

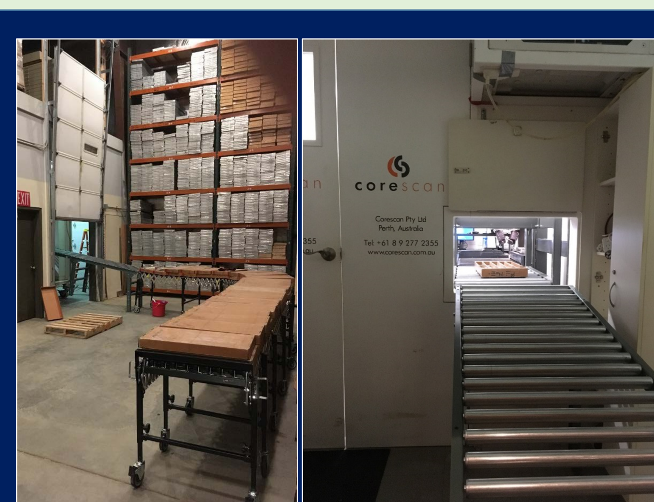


Corescan's Hyperspectral Core Imager 3 (HCI-3)

Corescan's hyperspectral core imaging system (Martini et al., 2017) integrates both Visible Near Infrared (VNIR) and Shortwave Infrared (SWIR) reflectance spectroscopy with high-resolution photography (50 μm) and 3-d laser profiling (20 nm resolution) to identify minerals, estimate mineral abundances and create textural images at 500 μm resolution. Corescan operates these systems in both fixed-location bureaus and mobile labs that are housed within shipping containers that can be deployed across the globe for on-site scanning services.



A Corescan mobile laboratory arrived at the DNR Drill Core Library in Hibbing on January 4, 2019



Production line for core box scanning. Boxes were fed one at a time into the lab. A 10ft box of NQ drill core (47.6mm diameter) typically took 12-13 minutes to scan.

Core was cleaned and staged for scanning in a heated prep room

Drill core was either scanned within its storage box, or (when necessary) transferred to wood trays (shown above). This tray also shows how different types of core material was staged for scans.

Data Collection

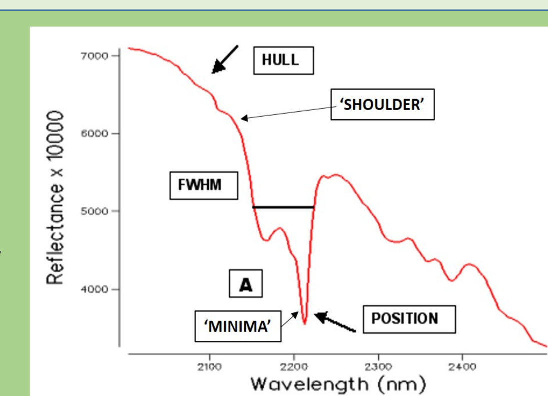
Hyperspectral imagery was collected from 4,862 meters of drill core over a five week-long period in Jan-Feb, 2019. Production rates required twelve-hour work days and seven-day work weeks. More than 1,600 boxes of core were pulled from archival storage, cleaned and staged for scanning, scanned, and then 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

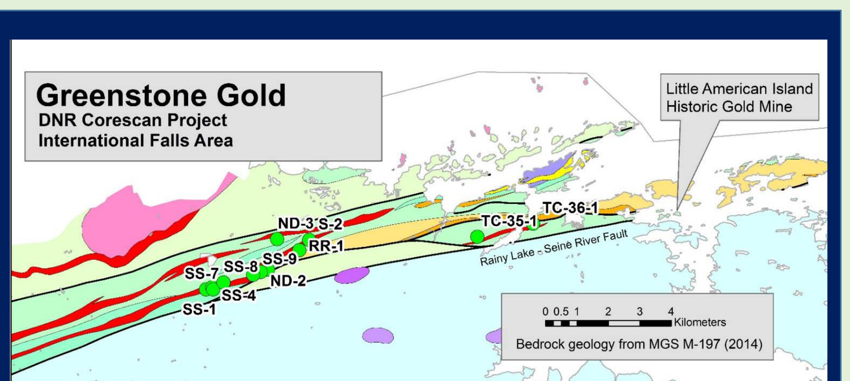
Spectral and radiometric calibrations are performed using NIST traceable rare earth and Spectralon® reflectance standards prior to and after scanning a tray. Hyperspectral image data sets are imported into proprietary Corescan spectral analyses software (Chameleon™) and analysed with a suite of project 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 spectral 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.



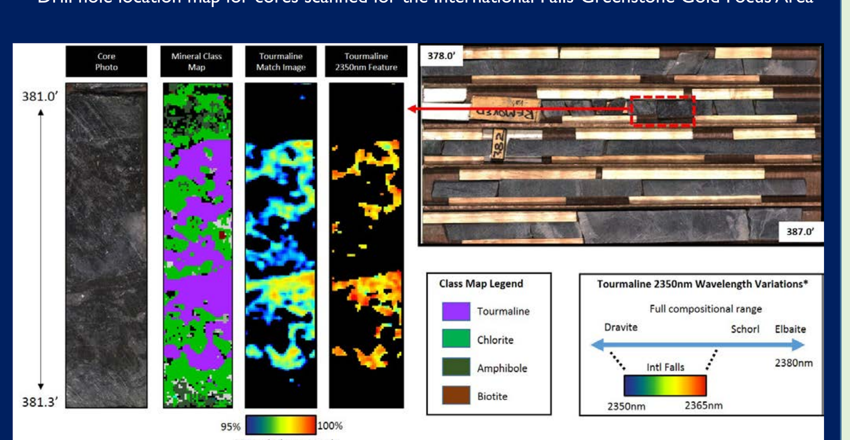
Example of a kaolinite 2200nm doublet feature showing many of the different characteristics of a spectrum that are used for mineral identification.

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 porphyoblastic 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.



Drill hole location map for cores scanned for the International Falls-Greenstone Gold Focus Area

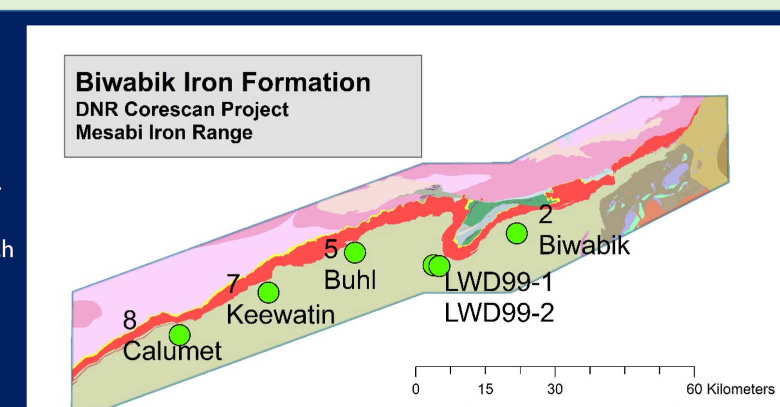


Hyperspectral imaging of tourmaline within an 8cm-long section of quarter-core from DDH TC35-1. This section is within a larger 4 foot (1.22m) core interval that assayed at 4020ppb Au. Variations in the 2350nm feature position (Bierwirth, 2008) suggest compositions within the dravite-schorl series.

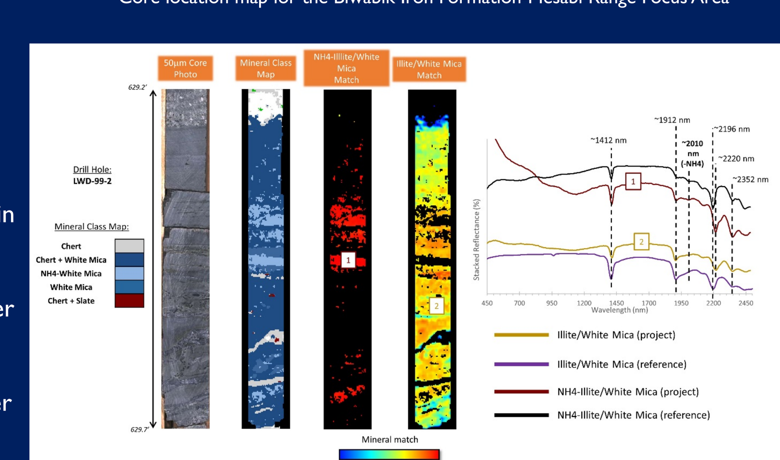
Early results: Biwabik Iron Formation

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.



Core location map for the Biwabik Iron Formation-Mesabi Range Focus Area

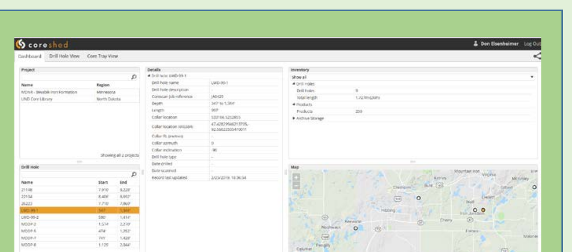


Illite/white mica and NH4-illite/white mica occurrences at the contact between Biwabik Iron Formation and Virginia Formation, based on spectral reflectance data

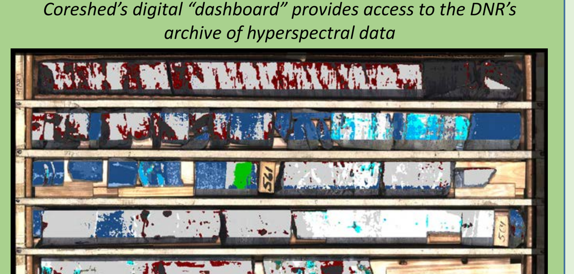
First-time Public Access to Coreshed Data

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.



Coreshed's digital "dashboard" provides access to the DNR's archive of hyperspectral data



Coreshed image of a box of core from the Sudbury ejecta layer (LWD99-1, 557-566ft.), overlain by interpreted mineral map.

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

This project was funded by the MN Dept of Natural Resources and the MN Dept of Iron Range Resources & Rehabilitation. We would like to thank Heather Arends and Brigette Martini for the hard work they put into making this collaboration possible. Scanning 16,000+ boxes of drill core was a significant undertaking that couldn't have been completed without the sweat, persistence, and sacrificed weekends of Nick Niemi, Doyle Birdsall, Doug Rosneau, Cheyanne Dusek, Andrea Reed, Glenn Melchert, David Dahl, Thomas Lee, Corrie Floyd and others at the DNR Hibbing Office.

Addison W.D., Brumpton G.R., Vallini D.A., McNaughton N.J., Davis D.W., Kissin S.A., Fralick P.W., and Hammond A.L. (2005) Discovery of distal ejecta from the 1850 Ma Sudbury impact event. Geology 33:193-196.

Bierwirth, P.N. (2008) Laboratory and imaging spectroscopy of tourmaline - a tool for mineral exploration. 14th Australasian Remote Sensing and Photogrammetry Conference, Darwin.

Canet C., Hernández-Cruz B., Jiménez-Franco A., Pi T., Peláez B., Villanueva-Estrada R.E., Alfonso P., González-Partida E., Salinas S. (2015) Combining ammonium mapping and short-wave infrared (SWIR) reflectance spectroscopy to constrain a model of hydrothermal alteration for the Acoculco geothermal zone, Eastern Mexico. Geothermics 53:154-65.

Frey B.A. (2012) International Falls Drill Core Descriptions and Chemistry, Koochiching County, Minnesota. Project 378 Open-File Report, Minnesota Department of Natural Resources, Division of Lands and Minerals, 39p.

Kokaly, R.F., R.N. Clark, G.A. Swayze, K.E. Livo, T.M. Hoefen, N.C. Pearson, R.A. Wise, W.M. Benzel, H.A. Lowers, R.L. Driscoll, A.J. Klein (2017) USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61p.

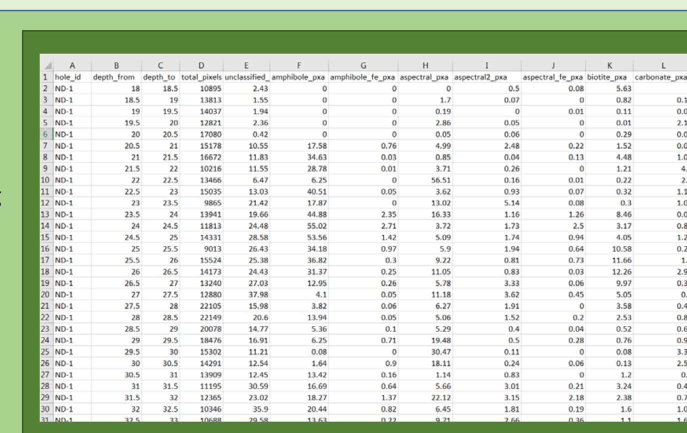
Jirsa M.A., Boerboom T.J., and Chandler V.W. (2014) M-197 Bedrock Geology of the International Falls and LittleFork 30'x60' Quadrangles, northern Minnesota. Minnesota Geological Survey, Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/166157.

Martini B.A., Harris A.C., Carey R., Goodey N., Honey F., and Tufilli N. (2017) Automated Hyperspectral Core Imaging – A Revolutionary New Tool for Exploration, Mining and Research. in "Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration" edited by V. Tschirhart V. and M.D. Thomas, p. 911-922.

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.



	A	B	C	D	E	F	G	H	I	J	K	L
1	hole_id	depth_from	depth_to	total_pixels	unclassified_	amphibole_pxa	amphibole_fe_pxa	aspectral_pxa	aspectral2_pxa	aspectral_fe_pxa	biotite_pxa	carbonate_pxa
2	ND-1	18	18.5	10895	2.43	0	0	0	0.5	0.08	5.63	0
3	ND-1	18.5	19	13813	1.55	0	0	1.7	0.07	0	0.82	0.17
4	ND-1	19	19.5	14037	1.94	0	0	0.19	0	0.01	0.11	0.04
5	ND-1	19.5	20	12821	2.36	0	0	2.86	0.05	0	0.01	2.14
6	ND-1	20	20.5	17080	0.42	0	0	0.05	0.06	0	0.29	0.01
7	ND-1	20.5	21	15178	10.55	17.58	0.76	4.99	2.48	0.22	1.52	0.05
8	ND-1	21	21.5	16672	11.83	34.63	0.03	0.85	0.04	0.13	4.48	1.01
9	ND-1	21.5	22	10216	11.55	28.78	0.01	3.71	0.26	0	1.21	4.4
10	ND-1	22	22.5	13466	6.47	6.25	0	56.51	0.16	0.01	0.22	2.9
11	ND-1	22.5	23	15035	13.03	40.51	0.05	3.62	0.93	0.07	0.32	1.18
12	ND-1	23	23.5	9865	21.42	17.87	0	13.02	5.14	0.08	0.3	1.05
13	ND-1	23.5	24	13941	19.66	44.88	2.35	16.33	1.16	1.26	8.46	0.04
14	ND-1	24	24.5	11813	24.48	55.02	2.71	3.72	1.73	2.5	3.17	0.84
15	ND-1	24.5	25	14331	28.58	53.56	1.42	5.09	1.74	0.94	4.05	1.24
16	ND-1	25	25.5	9013	26.43	34.18	0.97	5.9	1.94	0.64	10.58	0.24
17	ND-1	25.5	26	15524	25.38	36.82	0.3	9.22	0.81	0.73	11.66	1.5
18	ND-1	26	26.5	14173	24.43	31.37	0.25	11.05	0.83	0.03	12.26	2.94
19	ND-1	26.5	27	13240	27.03	12.95	0.26	5.78	3.33	0.06	9.97	0.35
20	ND-1	27	27.5	12880	37.98	4.1	0.05	11.18	3.62	0.45	5.05	0.5
21	ND-1	27.5	28	22105	15.98	3.82	0.06	6.27	1.91	0	3.58	0.46
22	ND-1	28	28.5	22149	20.6	13.94	0.05	5.06	1.52	0.2	2.53	0.84
23	ND-1	28.5	29	20078	14.77	5.36	0.1	5.29	0.4	0.04	0.52	0.66
24	ND-1	29	29.5	18476	16.91	6.25	0.71	19.48	0.5	0.28	0.76	0.97
25	ND-1	29.5	30	15302	11.21	0.08	0	30.47	0.11	0	0.08	3.36
26	ND-1	30	30.5	14291	12.54	1.64	0.9	18.11	0.24	0.06	0.13	2.52
27	ND-1	30.5	31	13909	12.45	13.42	0.16	1.14	0.83	0	1.2	0.7
28	ND-1	31	31.5	11195	30.59	16.69	0.64	5.66	3.01	0.21	3.24	0.48
29	ND-1	31.5	32	12365	23.02	18.27	1.37	22.12	3.15	2.18	2.38	0.78
30	ND-1	32	32.5	10346	35.9	20.44	0.82	6.45	1.81	0.19	1.6	1.08

Top left corner of a mineral abundance log for the twelve cores scanned for the International Falls-Greenstone Gold Focus Area. This 13,734 row spreadsheet uses pixel matches to estimate mineral abundances in 0.5 foot increments.

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.

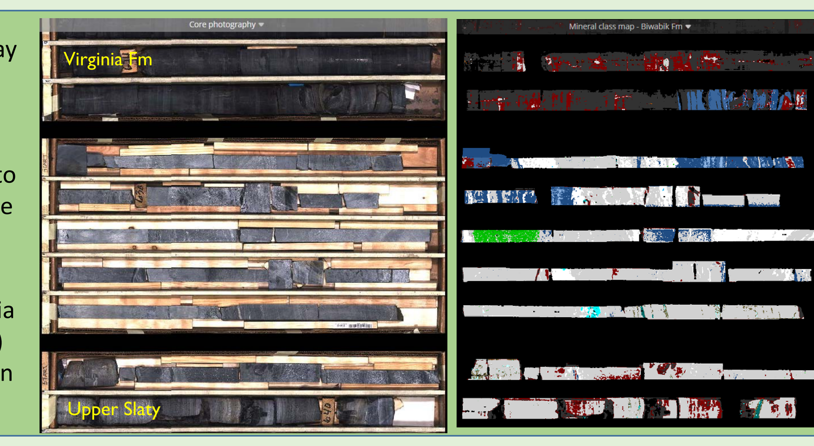
The figure below illustrates the strength of this type of data visualization. Modal abundance logs for International Falls-Greenstone Gold core ND-1 were calculated at 0.5ft increments for the full core length, with the relative abundances of chlorite, carbonate, epidote, prehnite and tourmaline plotted 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.

Drill hole: ND-1 (18' to 603')

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

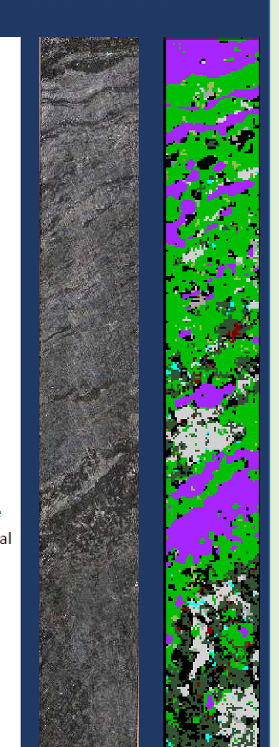
Mineral classification maps display the occurrence of all detected minerals in a single image map. Minerals that lack VNIR/SWIR absorption features are mapped as "aspectral". A combination of minerals can be mapped as a single unit when the observed spectra can't be further resolved.

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

Class Map Ranking: Highest Priority (top) to Lowest Priority (bottom)

Colour	Mineral Name
	Tourmaline
	Garnet
	Green Mica
	Sulfide
	Talc
	Epidote
	Prehnite
	Zeolite
	Biotite
	Fe-Carbonate
	Carbonate
	Amphibole
	Actinolite
	Sepiolite
	Hydrous silica
	Montmorillonite
	White Mica + Chlorite
	White Mica + Aspectral
	Gypsum
	White mica
	Chlorite
	Amphibole-Fe
	Pyroxene
	Chert
	Aspectral 2
	Aspectral
	Aspectral-Fe



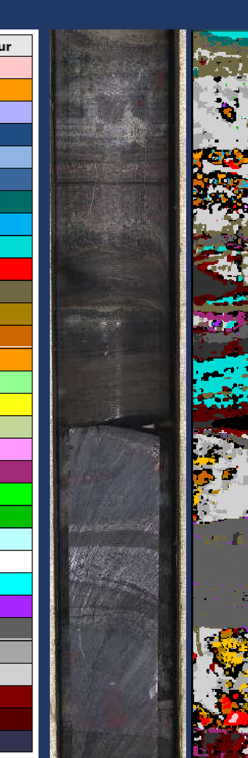
SS-9, 87.8-88.4ft

Preliminary Mineral Key — Biwabik Iron Formation – Mesabi Range

Class Map Ranking: Highest Priority (top) to Lowest Priority (bottom)

Mineral Name	Colour
Hematite + Quartz	
Goethite	
Montmorillonite	
Chert + Illite/White Mica*	
NH4-Illite/White Mica	
Illite/White Mica	
Fe-Carbonate	
Quartz	
Jasper + Fe-Carbonate	
Jasper	
Chert + Fe-Carbonate	
Microplaty Hematite	
Martite	
Fe-Oxide Mixture	
Fe-Talc	
Talc	
Greenalite	
Minnesotaite	
Stilpnomelane	
Fe-Chlorite	
Chlorite	
Carbonate + Silicate	
Chert + Carbonate*	
Carbonate	
Magnetite Mixture	
Magnetite	
Chert Mixture	
Chert	
Chert + Slate	
Slate Mixture	
Slate	

* Only displayed in the class map



LWD99-1, 855.3-856.2ft

Preliminary Mineral Key — Cuyuna Range Manganese

Class Map Ranking: Highest Priority (top) to Lowest Priority (bottom)

Colour	Mineral Name
	Chlorite
	Carbonate
	Opaline Silica
	Goethite
	Montmorillonite
	Nontronite
	White Mica
	Quartz
	Kaolinite
	Chert
	Jasper
	Microplaty Hematite
	Hematite
	Magnetite
	Sed (Type 1)
	Dark Sed (Type 2)

18723, 267.5-268.3ft

While the main focus of the six Mesabi Range cores was the Biwabik Iron Formation, intervals of overlying Virginia Formation and underlying Pokegama Quartzite were also scanned. Separate mineral keys have been created for the visualization of these units.

Mineral Name	Colour
Slate	
Slate Mixture	
Carbonate	
Fe-Carbonate	
Carbonate + Silicate	
Quartz	
Illite/White Mica	
NH4-Illite/White Mica	
Fe-Chlorite	
Chlorite	
Chert Mixture	
Chert + Carbonate	
Chert + Slate	
Chert	
Hematite + Quartz	
Goethite	
Montmorillonite	
Chert + Illite/White Mica	
Jasper + Fe-Carbonate	
Jasper	
Chert + Fe-Carbonate	
Microplaty Hematite	
Martite	
Fe-Oxide Mixture	
Fe-Talc	
Talc	
Greenalite	
Minnesotaite	
Stilpnomelane	
Magnetite Mixture	
Magnetite	

Preliminary Mineral Key Virginia Formation

Mineral Name	Colour
Quartz	
Hematite + Quartz	
Illite/White Mica	
NH4-Illite/White Mica	
Chert + Illite/White Mica	
Fe-Chlorite	
Chlorite	
Montmorillonite	
Slate Mixture	
Slate	
Carbonate	
Fe-Carbonate	
Carbonate + Silicate	
Chert + Slate	
Chert + Carbonate	
Chert + Fe-Carbonate	
Chert Mixture	
Chert	
Goethite	
Jasper + Fe-Carbonate	
Jasper	
Chert + Fe-Carbonate	
Microplaty Hematite	
Martite	
Fe-Oxide Mixture	
Fe-Talc	
Talc	
Greenalite	
Minnesotaite	
Stilpnomelane	
Magnetite Mixture	
Magnetite	

Preliminary Mineral Key Pokegama Quartzite