corescan

MnDNR Project – Corescan HCl-3 Data

2019

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Summary

A total of 1,622 core boxes holding 16,371 ft. of drill core (4,989.88 m) from six (6) separate projects was scanned for the Minnesota Department of Natural Resources (MnDNR) January 7th - February 10th of 2019 by the mobile Corescan® III hyperspectral core imaging system (Corescan HCI-3). The mobile HCI-3 (housed within a standard 20 ft. shipping container) was temporarily placed within the MnDNR Core Repository in Hibbing, MN. Over 33 days, optical core information was collected using a digital camera for photography (~50µm spatial resolution), imaging spectrometers for hyperspectral data (510 bands at ~4.0nm spectral resolution across 450-2500nm at 500µm spatial resolution), and a laser profiler for geotechnical parameters (~20µm vertical and 200µm spatial resolution). With approximately 200,000 spectra per metre of core material, this project represents a collection of more than 972 million spectral signatures.

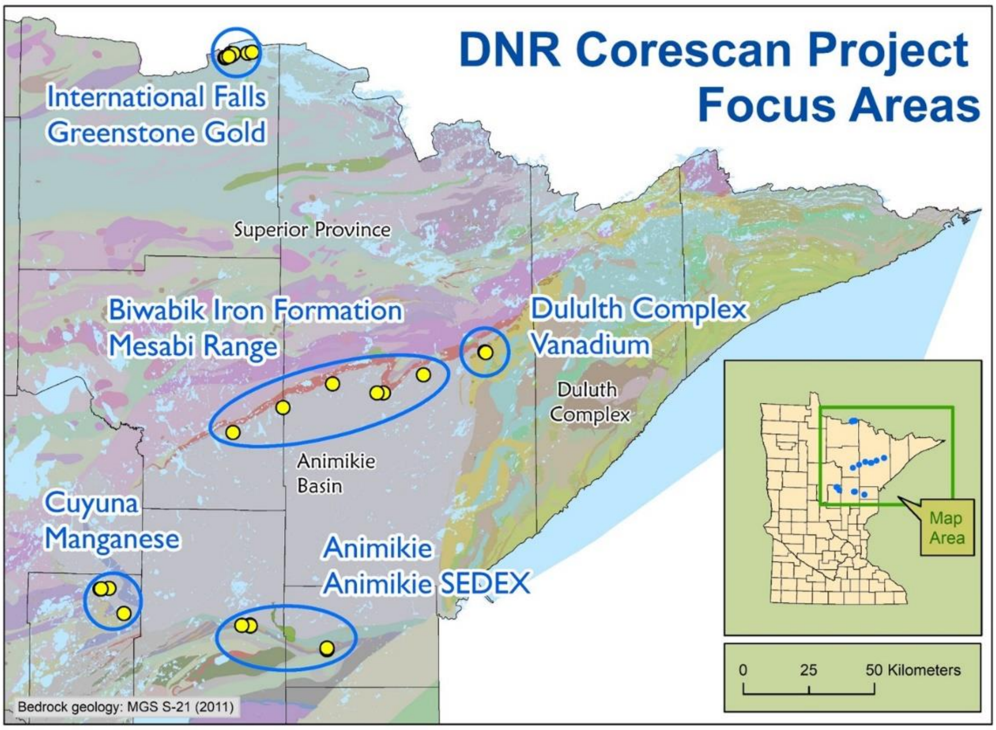


Figure 1. Location of six Focus Areas scanned for MnDNR including drill hole locations (see Table 1 for further detail).

For each Focus Area, three separate but concurrently collected datasets were geospatially co-located and then given secondary positional information based on reported depths from core blocks and/or rock markings. The digital core photography was delivered in three band red-green-blue (RGB) format jpeg2000 (.jp2) files. The hyperspectral data cubes (510 bands) were delivered with standard ENVI and ERMapper headers. Hyperspectral image products (true and false colour images) were delivered in jpeg2000 (.jp2) format. The laser profile data cubes (single band) were delivered with standard ENVI and ERMapper headers and digital surface map images delivered in jpeg2000 (.jp2) format.

In addition to the raw data cubes (core photos, hyperspectral images and laser profiles), the data has been processed for identification and mapping of mineralogy in various phases of alteration (e.g. primary, secondary overprints/replacement, etc.). Several image products were produced, including classification map images, individual mineral abundance match images, mineral chemistry composition images, crystallinity (or degree of crystalline order) images, multi-mineral classification map images, and geotechnical images (calculated from laser profile data). Note that due to the age of the core in this project, geotechnical algorithms were only applied on one drill hole (RR-1 from the International Falls Greenstone Gold project) as a demonstration of the potential deliverable laser profile data available for more recently drilled core. Each of these classification maps and images were provided as georeferenced jpeg2000 (.jp2) files (excepting the geotechnical images which are only accessible on Coreshed.com); image-based maps will open in most image visualisation/editing/processing software as well as within the ENVI environment for dynamic spatial linking between hyperspectral-based mineral maps, photos, and laser data.

Mineral identification, mineral composition, and crystallinity calculations were performed within the proprietary Corescan® software, Chameleon. Mineral identifications were primarily based on best-fit comparisons of Corescan hyperspectral signatures to the USGS spectral library (Kokaly et al., 2017), and then mineral identification was refined using best-fit comparisons with the MnDNR Focus Area specific spectral libraries. Copies of the bespoke MnDNR Focus Area spectral libraries derived from Corescan hyperspectral data have been provided as .txt files as an associated project deliverable.

In addition to image-based products, downhole mineral pxa logs (pixel abundance) were produced. These pxa logs represent mineral abundance over 6 inch (6") intervals. Pixel abundance logs are an accounting of all minerals identified in each pixel within a given interval divided by the total number of pixels from that interval (including unclassified pixels) which is then normalized to sum to 100%. This final resultant value is referred to as 'pseudo abundance' (pseudo because this is a surface technique and not whole-rock). Note that when a single pixel reports more than one spectrally active mineral, we assume that each mineral contributes equally to the associated spectral response (linear spectral signature mixing).

Final logs were produced for pxa mineral occurrence as well as for average compositional and crystallinity calculations over defined half-foot intervals. Where appropriate in core-based projects, simple geotechnical variables were extracted and quantified in the downhole logs including Breaks-per-Meter, Surface Roughness, and RQD. As mentioned previously, these geotechnical calculations were performed on a single drill hole from the International Falls dataset (RR-1), and is only available for viewing on Coreshed. The numeric geotechnical data was not exported, as the age and movement of these core samples precludes meaningful geotechnical extractions from the data. The geotechnical images have been included to demonstrate potential deliverables when scanning suitably preserved/protected core. Ultimately, downhole mineral and compositional logs were exported in .csv format and can then be readily import into databases or three-dimensional modelling software.

Scanned Samples

MnDNR supplied a series of core samples (1622 core boxes)[1] for scanning (Table 1).

	Scanned Samples		
Job	***Projects***	***Total Amount[2]***	***Depths***
JA0492	*Animikie*	*810 ft.*	*LM-13-01 (203-454ft.); LM-13-02 (395-465ft.); LM-13-03 (346-506ft.); LM-13-04 (146-475ft.)*
JA0465	*Animikie SEDEX*	*545 ft.*	*K-1 (36-200ft.); KL-4 (119-500ft.)*

JA0467	*Biwabik Iron Formation*	*4,911 ft.*	*LWD-99-1 (347-1,344ft.); LWD-99-2 (580-1414ft.); MGS-2 (1574-2270ft.); MGS-5 (474-1252ft.); MGS-7 (741-1428ft.); MGS-8 (1125-2044ft.)*
JA0464	*Cuyuna Range Manganese*	*1,130 ft.*	*18423 (145-328ft.); 18709 (340-540ft.); 18713 (178-375ft.); 18715 (254-599ft.); 18961 (284-489ft.)*
JA0466	*Duluth Complex Vanadium*	*2,099 ft.*	*LNG-001-2010 (54-794ft.); LNG-003-2010 (0-306ft.); LNG-011-2011(0-1053ft.)*
JA0429	*International Falls Greenstone Gold*	*6,881 ft.*	*ND-1 (18-603ft.); ND-2 (29-653ft.); ND-3 (19-409ft.); RR-1 (6-1,602ft.); S-2 (4-452ft.); SS-1 (11-588ft.); SS-4 (39-412ft.); SS-7 (34-722ft.); SS-8 (31-502ft.); SS-9 (53-400ft.); TC35-1 (80-462ft.); TC36-1 (3-403ft.)*

[1] Each core box contained approximately 10ft of core; standard core boxes had 5 core rows, and were 2ft long. Standard core width is HQ (~63.5mm diameter)
[2] Note that core amounts relate to actual physical core lengths rather than total scanned footage; total scanned footage was approximately 16,984 ft which includes core + core box (even if empty)

Table 1. Labels, amount and depths of scanned MnDNR project core.

Preparation

The core was checked for surface contamination (dust/mud) and lightly cleaned to ensure a compliant surface for scanning. Some project core was also quite old and needed to be checked for correct depth order and to make sure the best rock faces were aligned upward for data capture. Some core, particularly from older projects, had to be temporarily transferred to new boxes more suitable for scanning. Also, some core from more historic projects had to be propped up, or elevated in the e, to create consistent material height within each core box row, to ensure highest quality data capture. Staff from the MnDNR assisted heavily in these efforts.

Labelling/Identification

Depth markers from the core boxes were used as the reference for the spatial visualisation of the scanned core imagery. Final mineral logs were derived for the entire drill hole and are tagged with depth information.

Corescan: The Scanning Process and Products

Scanning was performed at the MnDNR Drill Core Library facility in Hibbing, MN using Corescan's HCI-3 system. The HCI-3 system is housed within a standard 20' sea container. This mobile laboratory is fully self-contained, comprising all sensors, core loading tables, computer processing hardware and software, and a work area for technicians and/or geologists (Figure 2A).

Figure 2A. Fully Mobile Corescan laboratory being delivered to the MnDNR Core Library; 2B. Placement in the interior of the Core Library and 2C. Internal view of the Corescan laboratory with Corebox translation table, imaging system and computing infrastructure.

The Corescan HCI-3 instrument performs three measurements over the core or other rock samples, i) high resolution core photography with a pixel resolution of ~50µm; ii) hyperspectral imaging across a 450nm - 2500nm range at ~4nm spectral resolution and ~500µm spatial resolution and iii) 3D laser profiling with a height resolution of ~20µm and spatial resolution of ~200µm. Figure 3 shows these three main Corescan products.

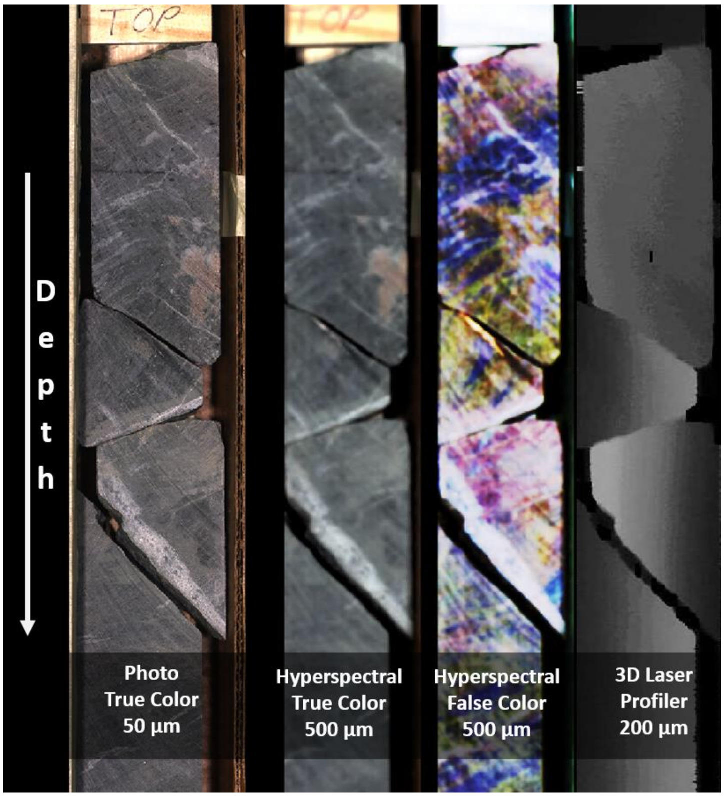


Figure 3. Corescan image products from JA0429, the International Falls Greenstone Gold project (hole SS-1) showing Photography, Hyperspectral data processed to true and false color imagery) and Laser Profile data (left to right). The core displayed in this image is ~63.5mm wide. Imagery shown taken from the Corescan online, digital core repository at www.coreshed.com

Calibration

Corescan's spectrometers are calibrated prior to the scanning of each row of core (or chips) using NIST (National Institute of Standard and Technology) Spectralon standards, including a REE standard to calibrate for instrument drift, as well as Spectralon bright and dark targets to calibrate for dynamic reflectance range. This calibration information was used to radiometrically correct the measured spectra (Figure 4).

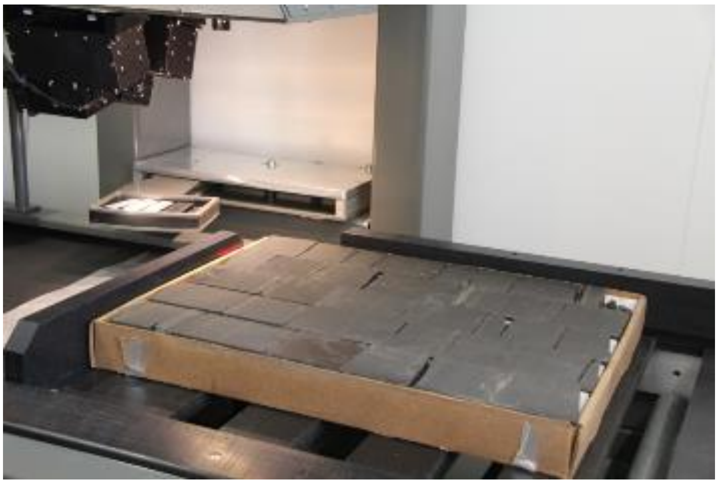


Figure 4. Automated radiometric and wavelength calibration using NIST Spectralon standards prior to scanning of each row of core.

Photography (50µm)

Core photography was acquired using a calibrated, high resolution camera that measures true RGB levels using 3 x independent CCD's. Core photography is accessible immediately via www.coreshed.com, and by request in digital hard copy form as jpeg2000 (.jp2) files from the MnDNR. Figures 5, 6 and 7 show examples of typical core photography and core box image arrangement.

Figure 5. 'Downhole' or vertical images showing Corescan RGB digital photography (50µm resolution) of core (core width ~63.5mm); Samples are (left to right) from the Animikie Focus Area (JA0492), the Biwabik Focus Area (JA0467), and the Duluth Complex Focus Area (JA0466).

*Figure 6. Corescan RGB Digital photography from downhole depth 454' to 464', from the Cuyuna Range Manganese Focus Area (JA0464). Core pieces are ~63.5mm wide. *This is an atypical core box – in older projects the core box did not have suitable integrity for scanning, so the core was temporarily transferred to a special wooden box (pictured above) for scanning, and then returned to the original box for storage.*

Figure 7. Corescan RGB Digital photography displayed in 'Stacked-by-section' format where imaged core boxes are 'stacked' digitally with depth; this imagery taken from a high gold grade zone in the International Falls Greenstone Gold Focus Area (JA0429), drill hole TC36-1 (193'-202').

Hyperspectral Imagery (500µm)

The Corescan HCI-3 measures the wavelength range between ~450 and 2500nm at a ~4nm spectral resolution (~510 spectral bands). The sensor optically integrates three discrete spectrometers in order to achieve its high spectral resolution, with each spectrometer having specifications similar to those listed below:

VNIR: 450nm - 850nm @ 4.1nm spectral resolution
SWIR-A: 850nm - 1600nm @ 3.2nm spectral resolution
SWIR-B: 1600nm - 2500nm @ 3.4nm spectral resolution

The hyperspectral data cube was delivered in BIL format files that may be read by third party software, such as ENVI. Digital, true colour images of the data are accessible via a web-server at www.coreshed.com using a free, publicly available email-based unique user login, as well as being available upon request to the MnDNR in jpeg2000 (.jp2) format. Figure 8 shows an example of an extracted spectral signature from hyperspectral core imagery.

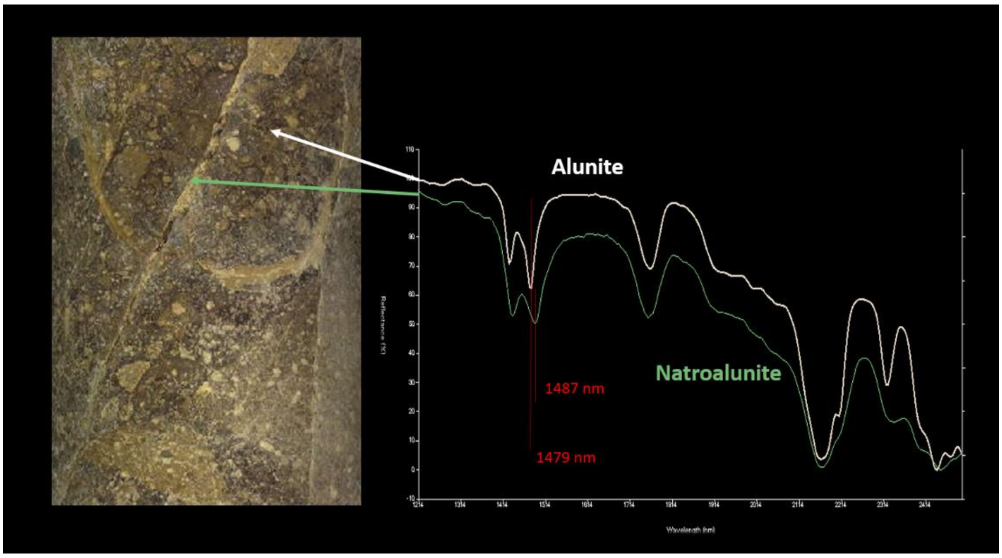
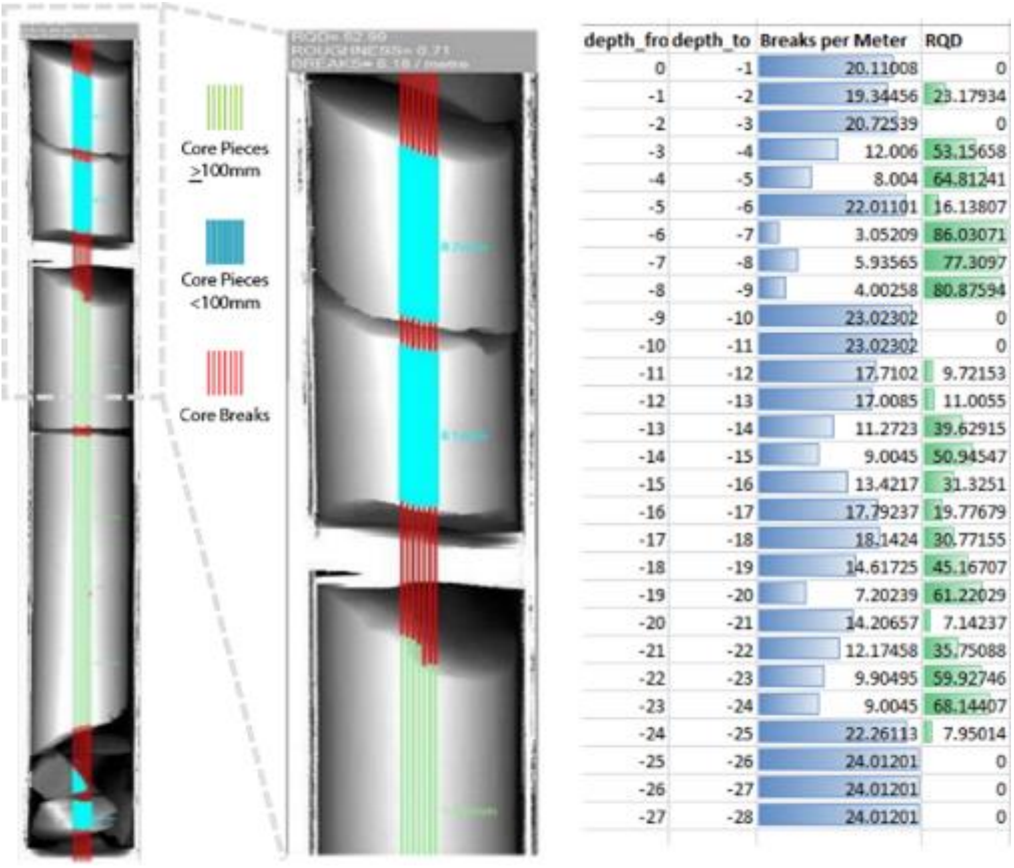


Figure 8. Each meter of imaged core has approximately 200,000 pixels and associated spectral signatures; the spectral signatures on the left correspond to alunite (in white) and natroalunite (in green) and were each extracted from a single pixel of the hyperspectral image data. Note that fine shifts in absorption feature minima (in this case, from 1479 to 1487 nm) reveals changes in molecular level chemistry of minerals.

3D Laser Profiling

The 3D laser profiler integrated with the Corescan HCI-3 system measured the height profile of the core (or other rock material) at a vertical resolution of 20 µm, a spatial resolution of 60 µm across core and 500µm resolution along the core. The profiler data was then gridded using a splining method to a standard 200um pixel size. The data can be used to derive a range of geotechnical parameters including Rock Quality Designation (RQD), Surface Roughness, and Fracture Frequency. Image data from drill hole RR-1 (with geotechnical measurements) are displayed at www.coreshed.com (Figures 3 and 9). As mentioned previously, the age and condition of the core renders it unsuitable for geotechnical calculation.



depth_fro	depth_to	Breaks per Meter	RQD
0	-1	20.11008	0
-1	-2	19.34456	23.17934
-2	-3	20.72539	0
-3	-4	12.006	53.15658
-4	-5	8.004	64.81241
-5	-6	22.01101	16.13807
-6	-7	3.05209	86.03071
-7	-8	5.93565	77.3097
-8	-9	4.00258	80.87594
-9	-10	23.02302	0
-10	-11	23.02302	0
-11	-12	17.7102	9.72153
-12	-13	17.0085	11.0055
-13	-14	11.2723	39.62915
-14	-15	9.0045	50.94547
-15	-16	13.4217	31.3251
-16	-17	17.79237	19.77679
-17	-18	18.1424	30.77155
-18	-19	14.61725	45.16707
-19	-20	7.20239	61.22029
-20	-21	14.20657	7.14237
-21	-22	12.17458	35.75088
-22	-23	9.90495	59.92746
-23	-24	9.0045	68.14407
-24	-25	22.26113	7.95014
-25	-26	24.01201	0
-26	-27	24.01201	0
-27	-28	24.01201	0

Figure 9. Left: Image showing laser profile results with automated detection and logging of Breaks per Meter and RQD. Right: Quantitative logs of measured geotechnical variables distributed as .csv files. Note this example is not from any MnDNR project; illustrative use only.

Corescan Mineral Abundance Logs

The downhole mineral logs (csv and pdf files) are reported in units of pixel abundance (pxa), which is the number of times the mineral of interest occurs within a given interval. This is also referred to as pseudo mineral abundance. This pxa value is calculated by dividing the number of pixels that report each VNIR (Visible Near-InfraRed) or SWIR (Short Wave InfraRed) detectable mineral by the total number of pixels in the interval. These abundances are normalized to 100%, but this normalization accounts for only NIR-SWIR active minerals. This product is considered semi-quantitative because it is solely a surface measurement, and also does not account for rock forming minerals which are inert to spectroscopy in the NIR/SWIR range. Inactive minerals are reported as 'unclassified', appear as black pixels in the classification map, and are not used in pixel abundance calculations. Mineral logs are delivered at a default of 6" intervals as well as matched to assay interval if provided.

Figure A.5 in the Appendix further describes the mineral pxa calculation; Figure 10 shows a typical subset of a log of identified mineralogy and mineralogical chemical parameters.

hole_id	depth_fro	depth_to	total_pixel	unclassifie	carbonate_	fe_carbonate	carbonate_silicate_	chert_fe_carbonate	chert_pxa	chert_slate_	chert_mixture	chorite_	fe_chlorite_	martite_	microplaty_hematite_	jasper_pxa	jasper_fe_	hematite_	goethite_	magneti
LWD-99-2	1394.5	1395	22860	2.966	0	2.299	0	52.137	8.845	16.01	0	0.113	0	0	0	0	5.072	0	0	1.0
LWD-99-2	1395	1395.5	14472	6.551	0	0.103	0	15.464	16.054	8.338	0.289	0.09	0	6.393	9.558	5.63	1.759	0.353	0	7.6
LWD-99-2	1395.5	1396	23852	13.211	0	2.209	0.235	16.757	28.314	1.378	0.358	0.305	0.119	3.569	3.089	3.489	12.728	0.109	0.421	1.5
LWD-99-2	1396	1396.5	23919	5.974	0.026	16.811	2.312	50.256	9.403	0.674	0	0.641	3.13	0	0	0	8.987	0	0	0.6
LWD-99-2	1396.5	1397	15256	2.917	0	3.184	0.249	26.085	39.115	8.089	4.391	0.343	0	0.154	0	0.095	10.19	0	0	0.2
LWD-99-2	1397	1397.5	20222	15.429	0.028	5.938	1.085	35.175	19.4	0.269	1.646	0.38	0.658	2.508	0.028	0.223	2.591	0	10.717	0.4
LWD-99-2	1397.5	1398	22261	14.37	0	0.264	0.069	8.039	5.55	0.249	0	0.394	0	33.333	0	20.093	12.785	0	1.715	0.7
LWD-99-2	1398	1398.5	22906	4.68	0	0	0	1.444	13.204	0.125	0	0.235	0	39.49	0.029	33.505	4.181	0	0.11	0.1
LWD-99-2	1398.5	1399	18880	3.792	0	0.058	0	3.667	0.192	0.422	0	0.11	0	65.294	0.029	17.017	3.173	0	0	0.3
LWD-99-2	1399	1399.5	23919	7.935	0.029	0.724	0.226	11.164	9.938	0.079	2.635	0.335	0.054	6.709	0.192	18.818	18.086	0	0	5.1
LWD-99-2	1399.5	1400	19338	14.815	0	1.875	0.105	9.451	30.989	2.454	4.037	0.153	0.043	7.605	1.009	7.299	12.503	0	0	2.0
LWD-99-2	1400	1400.5	20722	9.623	0	0	0	7.058	22.956	4.502	1.711	0.112	0	15.244	3.437	16.385	8.107	2.548	0.227	0.2
LWD-99-2	1400.5	1401	17605	9.406	0	2.458	0	43.189	3.462	2.151	0	0	0.041	0	0	0	17.326	0	0	3.2
LWD-99-2	1401	1401.5	23579	5.195	0	2.27	0.17	57.103	11.785	0.841	0	0.057	0	0	0	0.03	16.625	0	0	0.9
LWD-99-2	1401.5	1402	23585	11.083	0	0.729	0	22.991	25.207	6.111	0.235	0.073	0	6.194	0.128	2.056	22.628	0	0	0.3
LWD-99-2	1402	1402.5	18878	5.064	0	0.044	0.044	5.739	3.957	2.568	0	0.135	0	24.088	0.044	48.684	5.735	0.504	0.401	
LWD-99-2	1402.5	1403	23856	14.21	0	0	0	2.771	3.906	0.45	0.029	0.596	0.048	28.363	0.507	34.577	4.651	2.121	6.103	
LWD-99-2	1403	1403.5	20378	17.313	0	0	0	0	1.93	0	0	0.491	0	39.902	2.331	11.044	0.763	0.534	20.64	
LWD-99-2	1404	1404.5	11077	1.282	0	0	0	0	3.482	0	0.171	0	0	85.65	6.435	0.386	0.188	0	1.14	
LWD-99-2	1404.5	1405	23152	6.911	1.284	9.027	4.731	2.324	4.924	1.272	0	0.24	2.929	22.64	0.499	4.064	23.473	0	12.18	
LWD-99-2	1405	1405.5	23899	6.335	1.254	0.085	0.986	2.125	0.718	0	0	0.429	7.68	39.509	0	28.568	2.895	4.463	4.079	
LWD-99-2	1405.5	1406	14450	13.744	4.256	0.798	5.355	6.962	4.34	0.143	0	0.613	18.27	9.505	0	15.902	7.882	3.05	7.2	0.1
LWD-99-2	1406	1406.5	22976	2.08	0.504	0	0.071	0.041	0	0	0	0.694	2.346	68.147	0	15.306	1.07	4.421	0.545	
LWD-99-2	1406.5	1407	26646	1.4	0.586	0.195	0.163	0.03	0.046	0	0	0.618	4.018	51.211	0	23.14	0.581	16.792	0	
LWD-99-2	1407	1407.5	25282	0.38	0.031	0	0	0	0.307	0.179	0	1.195	0	46.927	0	26.208	0.125	24.473	0	
LWD-99-2	1407.5	1408	18514	0.378	0.275	0	0.117	0	2.098	0.114	0	0.972	0.55	29.795	0	24.051	0.829	40.773	0	
LWD-99-2	1408	1408.5	26867	0.104	0.021	0	0	0	0.62	0.046	0	0.553	0	43.787	0	30.852	0.073	23.945	0	
LWD-99-2	1408.5	1409	26867	0.51	0	0.038	0.283	0.133	3.133	0	0	0.868	0	24.491	0	15.293	0.414	54.818	0	
LWD-99-2	1409	1409.5	16881	0.853	0.047	0	0.311	0.248	5.054	0	0	1.004	0	27.616	0	38.976	0.425	24.563	0	
LWD-99-2	1409.5	1410	26785	0.306	0	0	0.09	0.466	6.11	0	0	1.375	0	28.011	0	38.781	2.92	21.889	0	
LWD-99-2	1410	1410.5	26867	0.409	0.162	0.064	0.759	0.395	7.745	0.017	0	0.928	0	28.405	0	58.135	0.509	2.474	0	

Figure 10. Semi-quantitative, downhole pxa mineral logs reported at an interval of 0.5ft. Data is delivered in .csv format for import into any third-party software packages. Data from the Biwabik project, drill hole LWD-99-2.

Corescan Geotechnical Data

The laser profile data maps and extracts three sets of geotechnical variables including a 'pseudo' RQD measurement (pseudo as it is an estimate of RQD and does not take into account factors such as drilling or mechanical breaks and as such requires additional supporting data in order derive true RQD)) and a breaks per meter calculation. Figure 9 shows an example from core. Note that the calculated geotechnical variables are reported within the visual laser maps (as seen in the figure at the beginning of each meter of core).

Corescan File Delivery Formats

The Corescan data was delivered in two separate packages including the raw, pre-processed data cubes (core photography, hyperspectral cubes, and laser profiles) and the processed data (mineral maps, composition maps, basic imagery [photos and hyperspectral], and laser profile imagery).

Pre-Processed Data: Data Cubes

For each project a set of pre-processed data cubes were produced which include the RGB photography (3 band data cube), the hyperspectral data (~510 band data cube), and the laser profiler data (1 band data cube). These data cubes are all standard BIL files and are geospatially referenced, and may be viewed within third party remote sensing software packages. Corescan data is delivered with both ENVI and ERMapper-compatible headers.

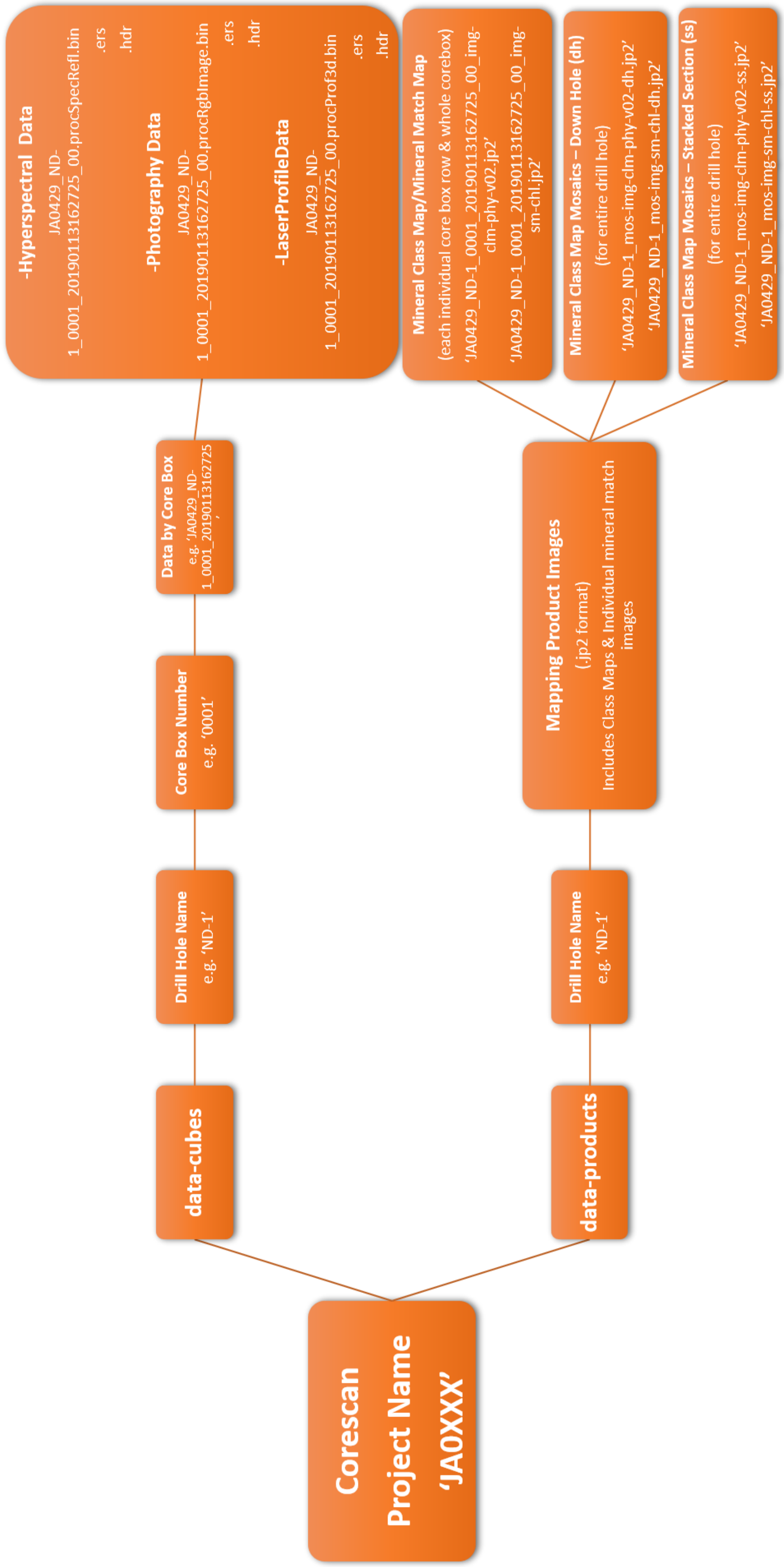


Figure 11. File structure for Data Cubes and Data Products showing the general divisions of data types and the naming convention for each file type (further described in Figure 12)

The datasets are divided by type of data (e.g. Hyperspectral Data). Every core box under each Project Name is assigned into a single directory. In the case of Hyperspectral Data, this translates to each row of scanned rock material, of every core box, collected under the single hyperspectral folder. The same is true for both Laser Profile data and RGB image data. The naming convention for these files reveals the Corescan project number, project name, box number, data of scan, time of scan, row number within the box, data type, and the file type (Figure 12).

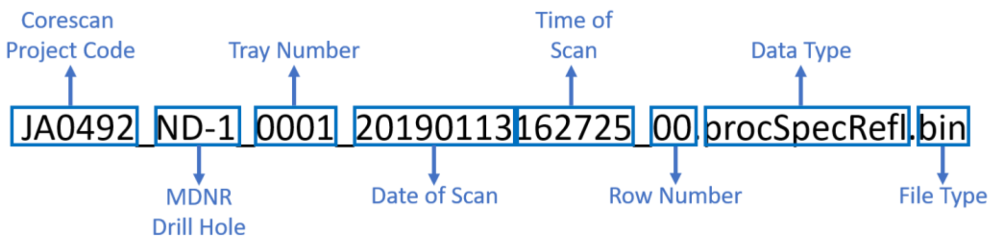


Figure 12. Typical naming structure for Data Cube files; hyperspectral data used as an example where Data Type changes to procProf3D and procRGBImage for Laser Profile and Colour Photography data respectively

For each core box (e.g. 0001), there are thus a set of corresponding photos, hyperspectral cubes and laser data, separated out by each individually scanned row (_00, _01, _02, etc.); thus, if the core box/tray that has been scanned has five rows, there will be five separate sets of image data.

Hyperspectral Data

Full 510-band hyperspectral image cubes were provided. These data are calibrated to reflectance via measurement of Spectralon® calibration targets. A third, NIST Spectralon, standard is measured to calibrate the spectrometer's wavelength values.

The 660, 560 and 468 nm hyperspectral bands, i.e. Red, Green and Blue, respectively, produce a 'true-colour' visual representation of the scanned rock material at the native 500 µm spatial resolution (Fig. 13). Each row of hyperspectral image data is approximately 450MB.

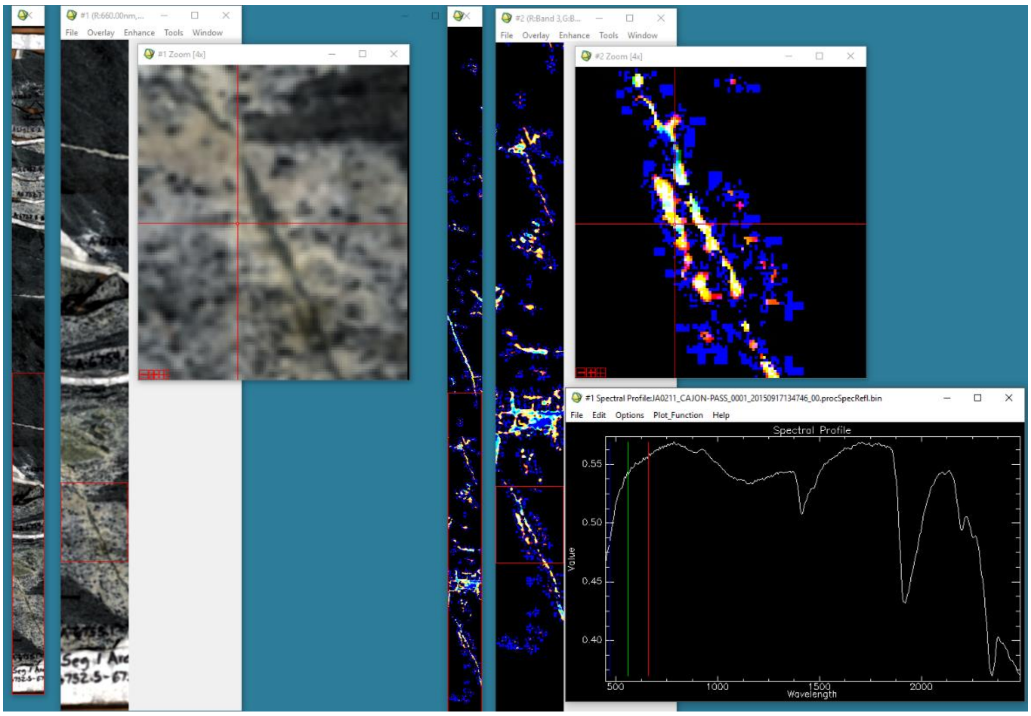


Figure 13. Corescan hyperspectral data displayed in true-colour, RGB (left) and hyperspectral-based, mineral match image for laumontite, where warmer colours are a stronger match to the USGS spectral library laumontite specimen (right), spatially linked and displayed within the ENVI software package; spectral signature at bottom right extracted from single pixel at center of cross-hair in 'Zoom' image; data shown is a general example and does not show MnDNR data

Laser Profile Data

Laser profile height data at ~20µm vertical resolution was collected concurrently alongside the hyperspectral data, and was gridded to 200 µm spatial resolution along the surface of the core. The laser measures surface variability and relative height variation. Due to the simultaneous nature of collection and the full spatial registration (Figure 14), other image products (including hyperspectral data and products, as well as RGB photography) can be overlaid or 'draped' on the laser profile data in order to render the data products in three dimensions (Figure 15). Note that some projects (particularly those that have been heavily sampled) have less meaningful laser profile data; the applicability of the 3D laser profile data is most obvious in the projects where whole, uncut, unsampled drill core is available for analysis. Each row of 3D profile laser data is approximately 8MB.

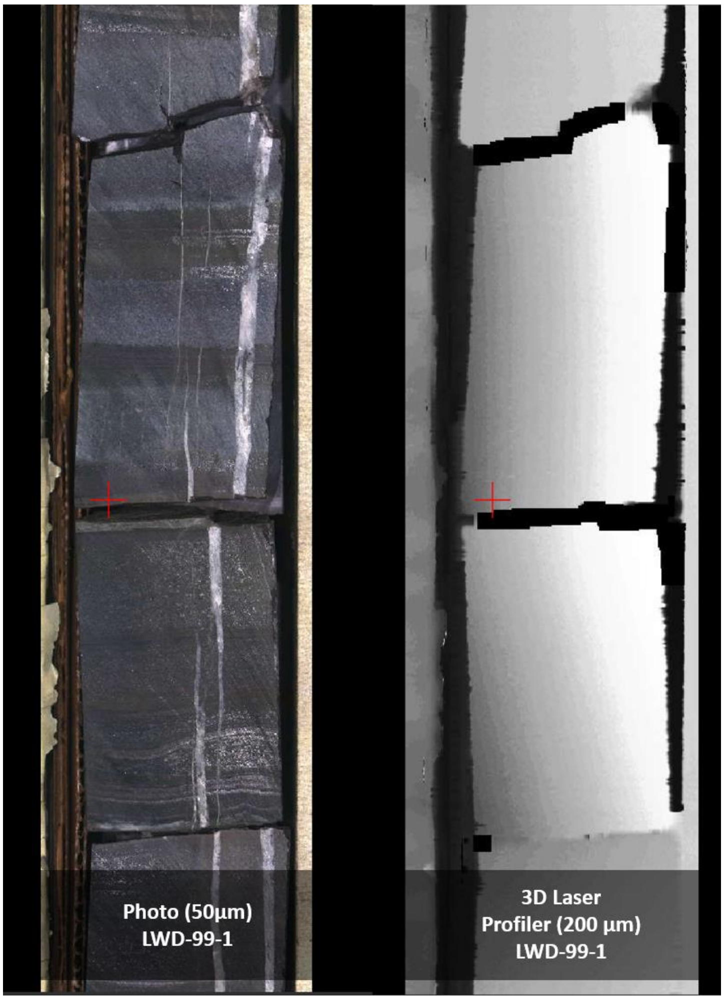


Figure 14. True-colour RGB photography (left) and 3D laser profile imagery (right) shown geospatially linked within Coreshed; dataset is JA0467, Biwabik (~1,262ft.)

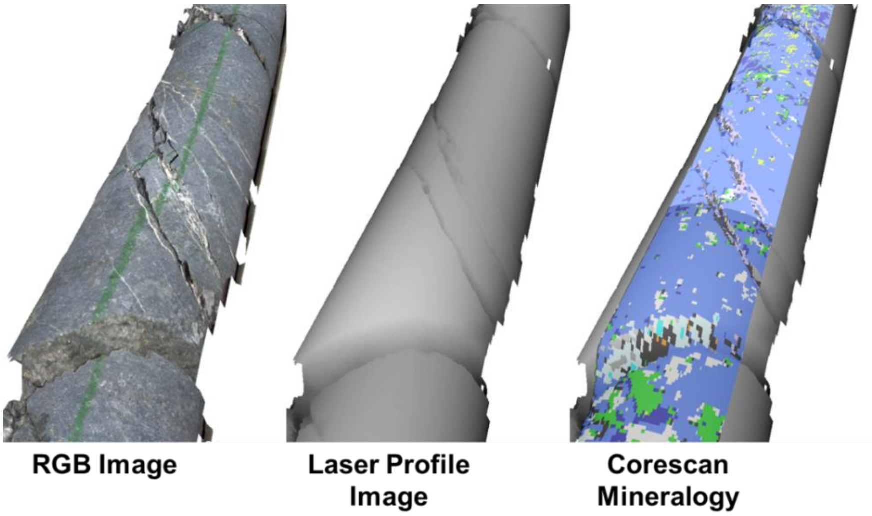


Figure 15. Corescan true-colour photography (left) 3D laser profile imagery (middle); hyperspectral-based mineral classification map draped on 3D profile images (right). Image credit: Harraden et al., 2019.

RGB Image Data

Three-band (RGB) colour photography at 50 µm spatial resolution was collected simultaneously alongside both the hyperspectral and 3D laser profiles (Figure 13 shows spatial link with laser data in the ENVI software environment). Each row of RGB image data is approximately 56MB in size.

Processed Data: Data Products

For every project, a set of Data Products was produced which include individual mineral maps (or match images) for every identified mineral in a given project (including project-dependent sub-species, composition and crystallinity maps), classification maps (that represent all mapped mineralogy and/or lithology), true and false colour hyperspectral images, true colour RGB photographic images, and 3D laser core profile images. Processed products were provided as georeferenced jpeg2000 (.jp2) image files. A summary of the generated data structure is shown in Figure 16.

Imagery/Maps by Row and Box

Individual images/maps are generated for every row separately. For example, the 'Animikie' project (JA0492) consists of four drill holes and a total of 94 boxes, all of which have five rows of core; each row has a separate set of Data Products including individual match image maps for every identified mineral (e.g. the match image map for chlorite ['chl'] indicated in the file structure in Figure 16), multiple mineral classification maps, true and false colour hyperspectral images, RGB photography, and core profiles. In addition, a collective full-box image is generated that represents every row within a single scanned box (Figure 17).

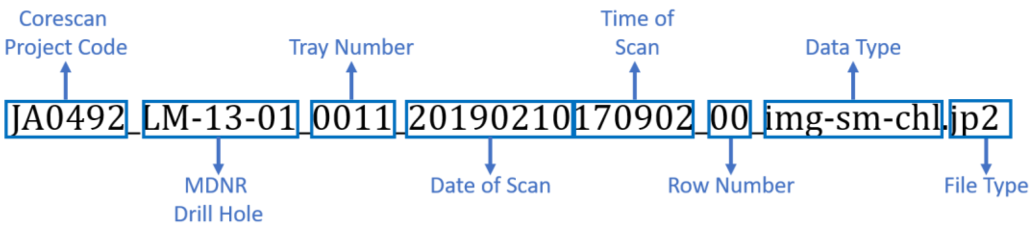


Figure 16. Typical naming structure for Data Products files; individual mineral match map for biotite used as an example where Data Type changes to reflect other individual mineral match map images, classification images, true and false colour hyperspectral images, RGB photography, or core profile images

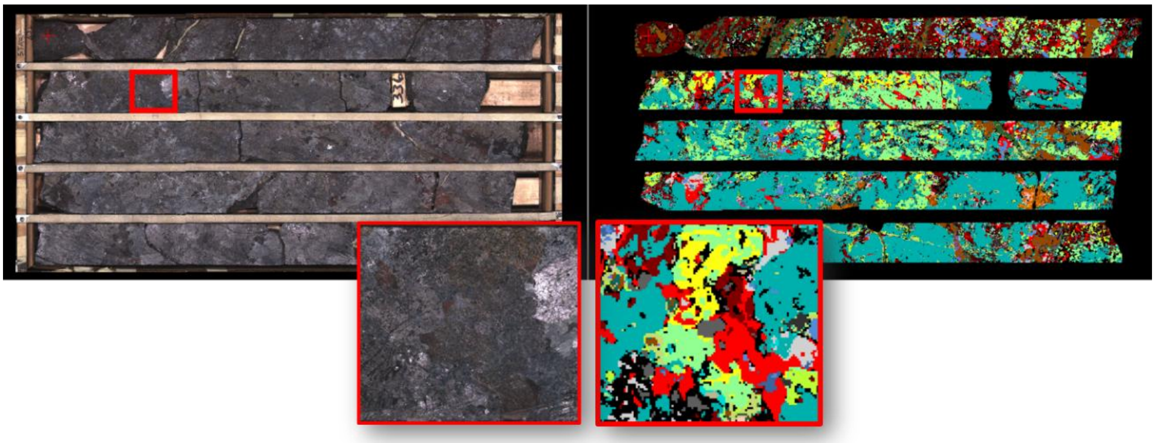


Figure 17. Data Product showing a multiple mineral Classification Map where all five rows of core are shown simultaneously; inset zoom images geospatially linked. Image is from the Duluth Complex Focus Area at ~103ft depth (JA0466).

Imagery/Maps by Drill Hole/Collection

All Data Products (individual mineral match maps, classification maps, true and false colour hyperspectral images, RGB photography, and core profiles) were also generated as single mosaic images that cover the entire drill hole. These single, project-wide images were produced in Down Hole format (annotated as 'dh' in the data type section of the data product file names) and in Stacked Section format (annotated as 'ss'; Figure 18). File structures and naming conventions are shown in Figure 19.

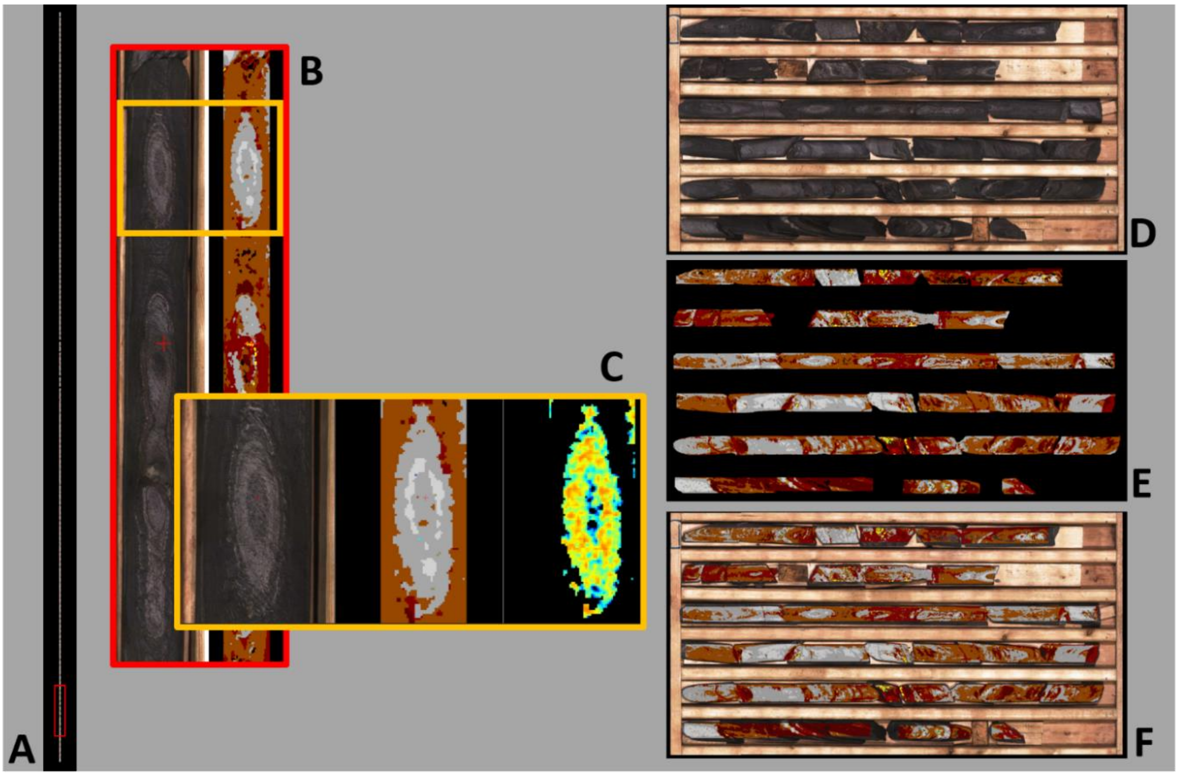


Figure 18. Mineral Classification Maps displayed in Down hole (dh) mode (A, B, C) and in Stacked Section (ss) mode (D, E, F) within the Coreshed environment. 18A displays all of drill hole K1 from the Animikie SEDEX project; 18B shows a zoom in on a length of core from box 13 at a depth of ~181' (location shown outlined in red on 18A); 18C is a further zoomed in view of a chert nodule with photography, classification map and match image for chert (location outlined in orange on 18B); 18D is photography of a single core box (box 13) displayed in stacked section; 18E is the classification map of box 18; 18F shows classification from 18E overlaid on photography of 18D. All images are stored as .jp2 files and will open in image-based software programs such as ENVI.

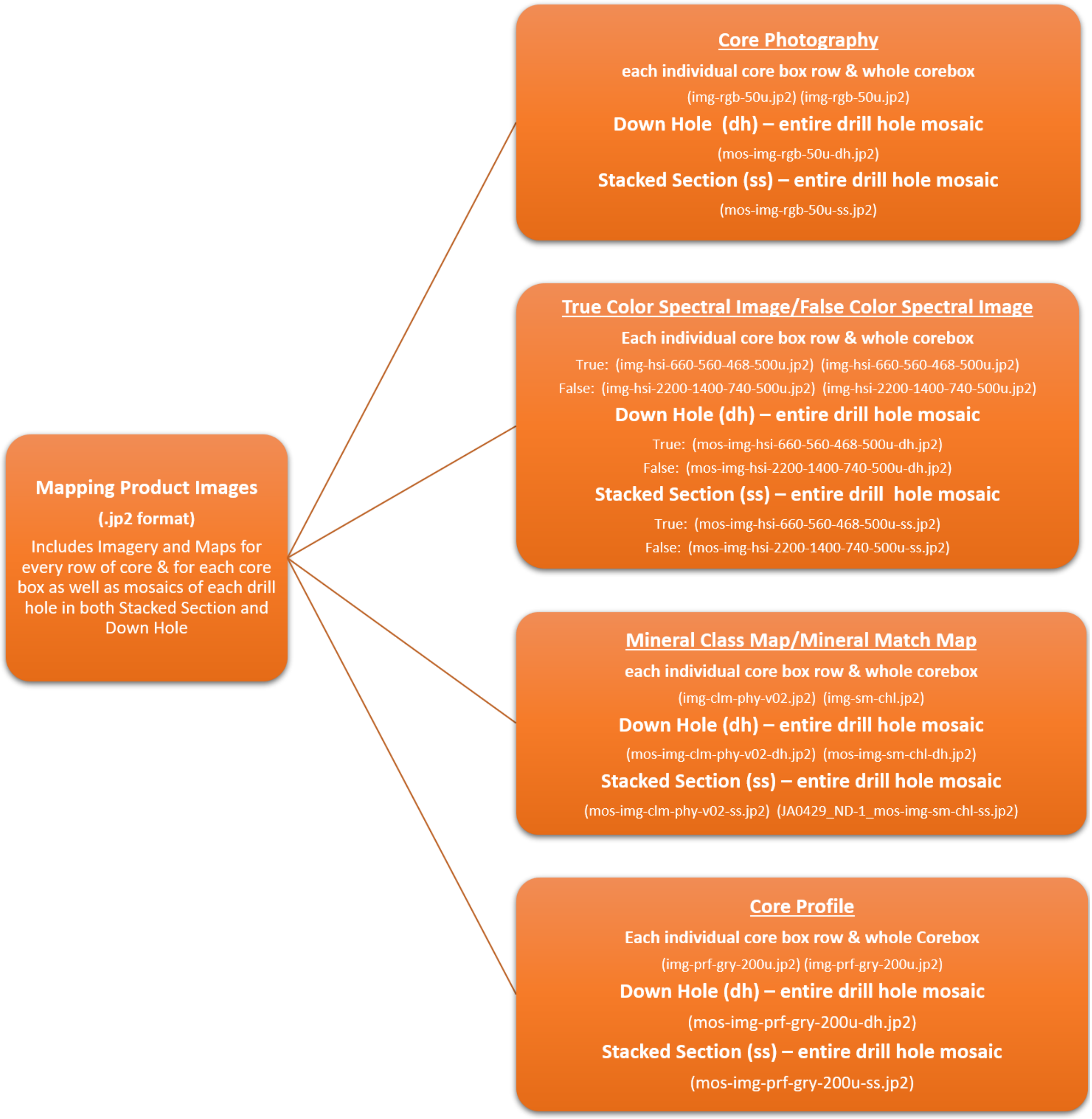


Figure 19. Data Products file structure and naming conventions.

References

Cassady L. Harraden, Matthew J. Cracknell, Lett James, Ron F. Berry, Ronell Carey, Anthony C. Harris; Automated Core Logging Technology for Geotechnical Assessment: A Study on Core from the Cadia East Porphyry Deposit. *Economic Geology* doi: https://doi.org/10.5382/econgeo.4649

Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Lowers, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., https://doi.org/10.3133/ds1035.

Appendix

Mineral Matches and Coreshed Images

A mineral map image is the end product of the mineral identification procedure, where the quality of the spectrum measured from each sample (pixel) is quantified in relation to a library spectrum (i.e. "goodness of fit"). If the sample spectrum matches the library spectrum exactly, this yields a match result of 1; conversely, if the sample spectrum is an exact mismatch from the library spectrum, the result will equal 0.

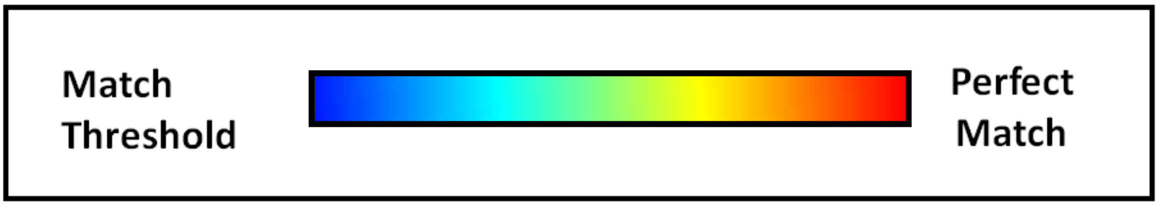


Figure A.1 Generalised explanation for mineral maps.

Many factors can influence the spectrum of a mineral, including grain size, crystallinity, compositional variations and mineral mixtures (e.g. a single pixel may contain two or more minerals that are mixed in a single spectrum). Due to these factors, the spectral match procedure may not return a perfect match (e.g. a value of 1), but a relatively high value may be returned if the spectrum primarily characterizes that mineral. Corescan geologists adjust the match criteria to find the best combination of features to characterize each mineral in a given project. The lowest acceptable value returned from the comparison of a sample spectrum to a library spectrum is called the *match threshold.* Minerals may be assigned different match thresholds because they have a different spectral response. These thresholds are set following a detailed examination of the dataset a process which relies on specialized skills in both image processing and spectral interpretations procedures. Most of the match thresholds Corescan geologists apply are equal to or greater than 0.90, or a 90% match.

The result of the spectral match procedure is then visualized in the mineral maps/images seen on Coreshed™. A perfect match is coloured red, a spectral match equal to the match threshold is coloured blue and every match in between follows the RGB gradient as shown in Figure A.1. If the match quality is less than the match threshold, then that pixel is coloured black. For example, the match threshold for sericite in the data example below is 0.92, so the legend for the calcite mineral map/images will appear as shown in Figure A.2.

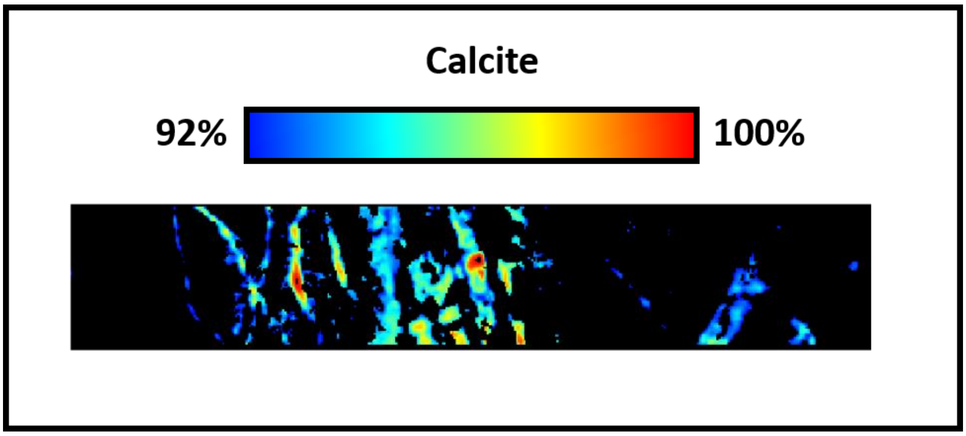


Figure A.2 TOP: Legend for a calcite mineral map/image with a match threshold of 0.92. BOTTOM: Snapshot of Calcite mineral match map from a drill hole where the pixels that represent pure Calcite are red, those that represent a 92% spectral similarity are blue and everything in between is coloured with an RGB gradient. Any pixel that returns a match score of less than 92% to the Calcite library spectrum is coloured black.

The thresholds for the mineral matches and the contrast stretches for images are consistent across individual projects. If improvements of matches and thresholds are made during a project, the spectral geologists re-process all of the products in the project. Thresholds, for mineral matches and spectral parameter images (wavelength, depth and crystallinity images), are therefore always consistent across a project, but not necessarily between different projects/deposits.

Mineral Classification Maps

The purpose of the classification map (or 'class' map) is to compile the multi-dimensional hyperspectral mineral images into a single product for a quick visual overview of trends in the data. The class map algorithm considers the minerals matched at each pixel and then allocates the class colour of the mineral with the highest priority for each specific pixel. A schematic example of this procedure is demonstrated in Figure A.3. Figure A.3. also demonstrates the influence that a change in the priorities of a group of minerals may have on the final mineral class map.

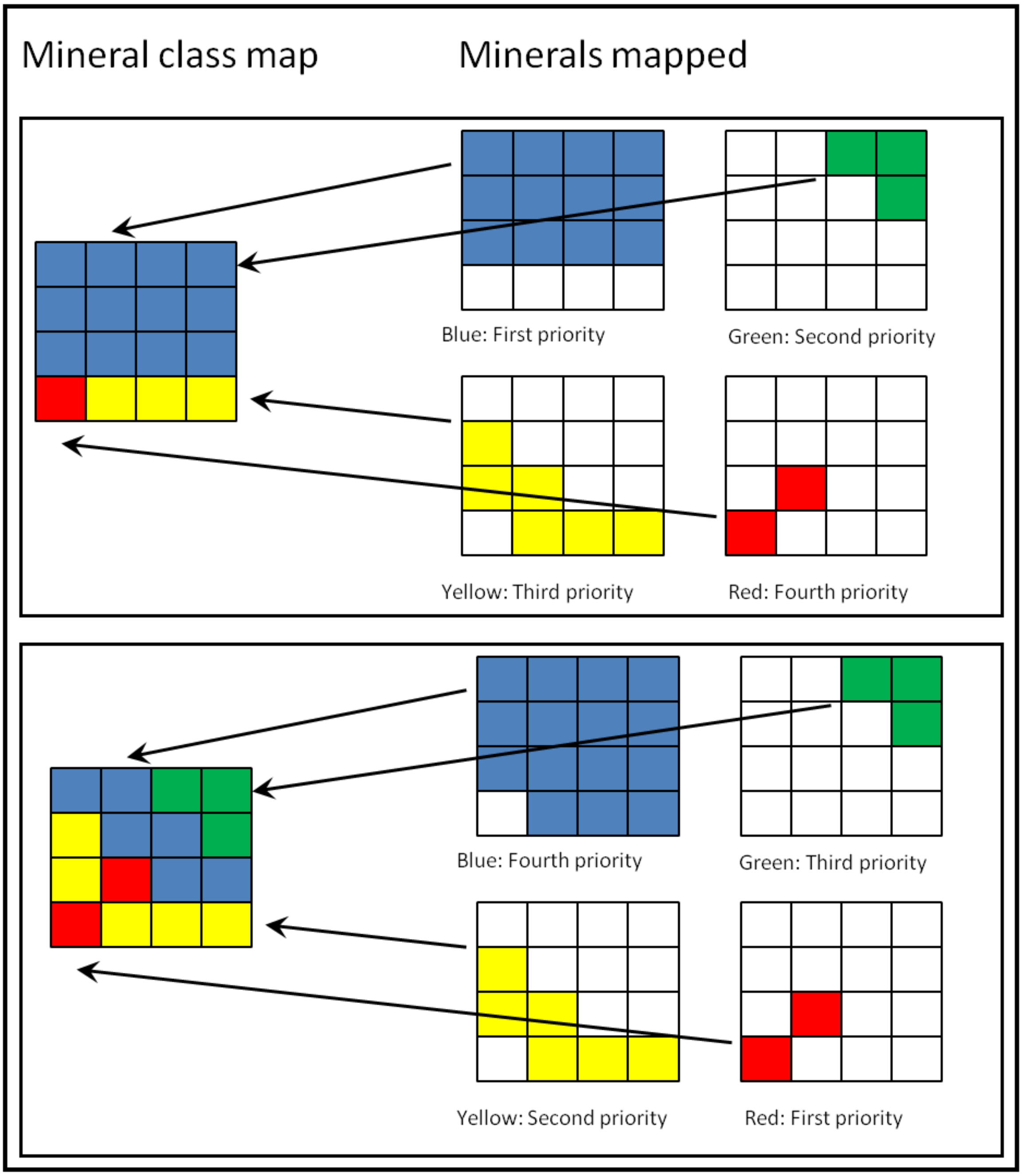


Figure A.3 Corescan mineral class maps and the effects of the priority ranking of minerals on the final product.

Mineral Abundance Logs

The mineral log algorithm checks each pixel against the list of library minerals, and a value of 1 (one) is assigned to each individual mineral occurring at that specific pixel. The combined pixel count of each individual mineral is then divided by the total amount of pixels in the interval. Figure A.4 summarises the calculation of the logs in an example of three arbitrary minerals over an interval of 10 pixels (while the 1m intervals used for a typical scanning project contain on average 150,000 pixels/metre).

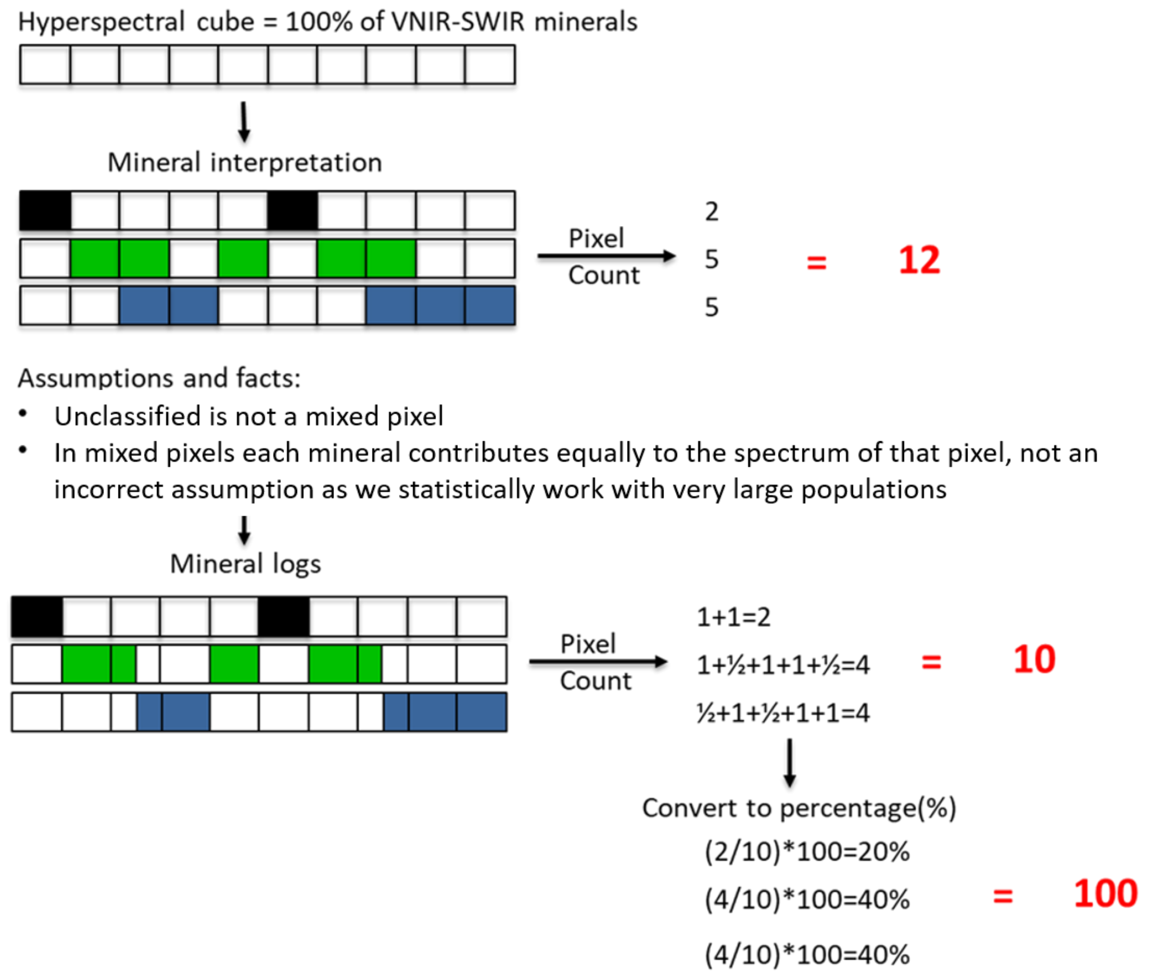


Figure A.4 Calculating log values for three minerals for a 10 pixel interval.

Spectral Reference Library

Mineral identifications are generally based on comparisons of Corescan hyperspectral image spectral signatures to the USGS spectral library (Kokaly et al., 2017), while mineral mapping is accomplished using image-derived spectral signatures. Spectral libraries (with image-extracted signatures) are generated for each project and provided as .csv files. The USGS Spectral Library can be found online at: https://crustal.usgs.gov/speclab/QueryAll07a.php corescan

corescan.com.au