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HyLogger 3 components and pre-processing: An overview

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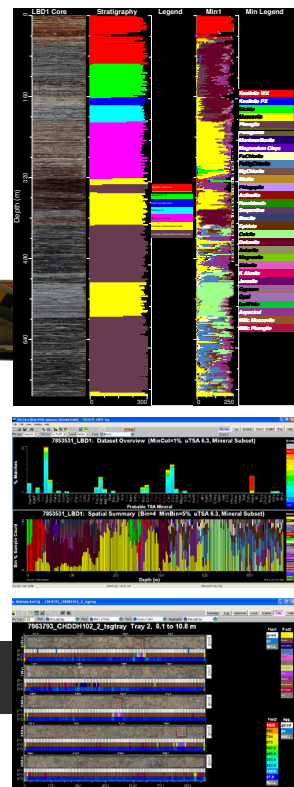
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Peter Mason and Jon Huntington

The Northern Territory Geological Survey (NTGS) has received a HyLogger™ instrument (**Figure 1**) as part of its participation in a national collaborative research infrastructure project, funded by the Federal Government's "National Collaborative Research Infrastructure Strategy" (NCRIS) within the Department of Innovation, Industry Science and Research. Other parties to the collaboration include CSIRO and all the other State Geological Surveys. The project is the first of its kind in the world.

The HyLogger[1] is a tool developed by CSIRO to improve the efficiency, productivity and objectivity of drill core logging by using reflectance spectroscopy to extract the mineralogy of drill cores and chips. Reflectance spectroscopy is used to determine diagnostic spectral features caused by molecular vibrations indicative of the chemical bonds in crystalline minerals.

Depending on the wavelengths used, reflectance spectroscopy can identify various minerals common to many geological units and hydrothermal alteration assemblages, including, for example:

- phyllosilicates
- amphiboles
- carbonates
- sulfates
- iron oxides
- silicates (quartz, feldspars, pyroxenes, garnets, and olivines).

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1 HyLogging, HyLogger, TSG and TSA are trademarks of the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Figure 1. NTGS' HyLogger 3-7 at the Darwin Core Facility, Winnellie. The setup shows conveyor ball rollers for moving core trays to the HyLogger from the core store, plus the HyLogger Operator's workstation with monitor and keyboard facing the HyLogger.

Semi-quantitative mineralogy and associated mineralogical parameters such as alteration intensity, 'crystallinity' and chemistry can also be extracted or inferred from the HyLogging data.

The HyLogger instrument

The CSIRO HyLogger rapidly measures reflectance spectra for contiguous 8 mm pixels along the core and also captures continuous high-resolution (0.065 mm per pixel) digital colour imagery of drill cores in their original trays (**Figure 2**). A six-section core tray takes about four minutes to log, and a maximum of about 700 m of core theoretically can be logged per day on a short burst. In practice, workflow and human issues result in an average of around 300m per day being sustained over long periods. No sample preparation is required, other than ensuring the core is clean and dry.

The current HyLogger consists of four principal components:

- A robotic x/y table for core / chip tray translation.
- A laser profilometer that measures core height at 0.2 mm resolution, which is used to detect core breaks and fractures, and locate empty portions of core trays that are then masked out.
- Three coupled spectrometers, covering the electromagnetic spectrum from visible-near-infrared (VNIR) to shortwave-infrared (SWIR) wavelengths (380–2500 nm) and thermal infrared (TIR) wavelengths (6000–14500 nm) for determining mineralogy.
- A high-resolution digital linescan camera.

The HyLogger 3-7 has a continuous-motion table that moves at 48 mm/sec. It is equipped with instruments that measure three things: VNIR / SWIR / TIR reflectance spectra, digital colour imagery and core height. It yields continuous coverage of these three parameters along a 1-dimensional profile and is typically set up to traverse along the middle of each core section in a core tray. It produces a set of raw data files per core tray and CSIRO-developed specialist processing software, called "The Spectral Geologist" (TSG), takes all three data streams from these raw files, cleans them up as necessary, and puts them into an environment where they can be used together for geological interpretation.

Figure 2. NTGS' HyLogger 3-7 about to scan a core tray.

HyLogger data components

Spectra

The HyLogger has three spectrometers – a silicon-detector grating spectrometer for the [380, 1072] nm VNIR interval; an InSb-detector FTIR (Fourier Transform Infrared) spectrometer for the [1072, 2500] nm SWIR interval and a further FTIR spectrometer with a HgCdTe photoconductive detector for the [6000, 14500] nm TIR interval. Functionally the user can think of the VNIR and SWIR spectrometers as one, because they see the same surface and their spectra are spliced together by the time the user receives them. The TIR spectrometer is a new instrument and its viewpoint is about 100mm down-track from the VNIR and SWIR spectrometers. The TIR and VNIR / SWIR spectrometers are synchronised by software. The InSb and HgCdTe detectors require liquid-nitrogen cooling.

The VNIR / SWIR spectrometers do not measure reflectance directly; they measure uncalibrated radiance. Each measurement includes 'dark', shutter-closed spectra and some spectra from a Teflon transfer standard (located in front of the core tray). These are used, along with an external Spectralon standard calibration file, to convert radiance to absolute reflectance. VNIR and SWIR spectra are radiometrically and spectrally corrected by the time they are imported into TSG.

The TIR spectrometer also doesn't measure reflectance directly. Its spectra are converted to approximate reflectance by the HyLogger using per-tray calibration spectra, in a similar way to the VNIR / SWIR spectra but also designed to remove the ambient temperature of the sensing environment. On import, TSG backs out the HyLogger's approximate correction and does a more rigorous correction using the per-tray calibration spectra in conjunction with blackbody and gold-standard measurements. (A blackbody measurement cycle is normally run at the start of the day.) This correction takes the spectra to calibrated radiance, then bidirectional reflectance. Immediately after the import, TSG runs TSA (The Spectral Assistant) on the TIR spectra. In addition to delivering unmixing results, TIR TSA models a temperature-difference component. (It gives the difference in temperature between the sample being measured and the thermal background.) This component is used to complete the TIR reflectance correction.

The spectrometers measure 12 spectra per second, or one spectrum for each 4 mm at the standard table speed of 48 mm/sec. However, the spectral *footprint* isn't 4 mm; it's about 12 mm along-track and about 8 mm across-track. This means that there is considerable overlap between neighbouring spectra. Currently, for a HyLogger-3, two adjacent spectra are averaged together to improve the signal-to-noise ratio and they thus span 18 mm of core along track (due to the fact that the core is moving as its spectra are being recorded).

Imagery

The HyLogger has a Basler piA1900-32gc camera for colour imagery. It takes 12 frames per second, or one for each 4 mm. A frame is about 120 mm wide and 6.5 mm long. The camera's field of view is almost always sufficient to span the full cores' width. The excess length (6.5 mm versus 4) helps in the frame mosaicing process later on. The camera is set up to yield a resolution of about 15 pixels per mm, but it is a Bayer-filter camera, so its true resolution is more like 10 pixels per mm.

Supplementing the main image data stream, one 'dark' shutter-closed and three Teflon frames are measured for later image correction.

The camera is positioned 100 mm behind the VNIR/SWIR spectrometer but its output is registered to the other data streams upon import.

Surface height

The HyLogger has a simple laser profilometer for measuring core height in mm above the table surface, at a rate of 768 measurements per second or 64 per 4 mm of movement. The profilometer measures just a single point, yielding a profile along the direction of travel. It shines a small laser spot down onto the core and estimates core height by triangulating the position of this spot as seen from a small angle. The HyLogging operator normally enters a 'tray height' so that the height can be corrected to height-above-tray-bottom later on.

The profilometer is positioned 100 mm in front of the VNIR/SWIR spectrometer. Across-scan, the profilometer position is about the same as the middle of the spectral footprint. The most valuable use of the profilometer data stream is to build a mask indicating where there is no core, or only rubbish in the tray bottom. This prevents the various mineral identification / characterisation algorithms from interpreting rubbish, when there is little or no core present.

Raw HyLogging data

Raw data output includes the following set of files per measurement, where a typical measurement is one core tray. For a HyLogger-3 this set is called 'the HyLogging SDS format':

- One SDS binary file containing absolute reflectance spectra, along with calibration, location and diagnostic data.
- One SDT binary file containing TIR approximate-reflectance spectra along with calibration, location and diagnostic data.
- One AUX text file, describing the measurement.
- One WVL text file, containing the VNIR and SWIR channels' wavelength centres.
- One WVT file containing the TIR channels' wavelength centres, in nanometres.
- One WVN text file containing the TIR channels' wavelength centres, in wavenumbers (a straight conversion).
- A JPM binary file for each core section, containing the image frames for that section.
- One PFC binary file, containing profilometer measurements.
- One JPG file, containing a dark, shutter-closed camera frame for image correction.
- Three JPG files of Teflon frames for image correction.
- One TRF text file, containing the correction gains that were used to convert radiance spectra to absolute reflectance.
- One RAD file containing blackbody, gold-standard and other calibration measurements for TIR correction.

Introducing TSG's involvement with HyLogging data

CSIRO has developed and commercialised 'The Spectral Geologist Suite' (TSG) of software, which can import, process, analyse, plot and visualise hyperspectral data collected from a variety of remote sensing spectrometers, including the HyLogger[2]. There are several versions of TSG with varying degrees of functionality; TSG-Viewer is freely available software for viewing (but not editing) TSG datasets. TSG-Core software allows simultaneous interactive analysis and product generation from all the data collected. The HyLogger initially produces a complicated package of raw data files (as listed above) and none of its data streams is ready to go. This package of data is referred to as Level 0 data. The HyLogger's primary purpose is to take measurements and this raw file format suits its purpose. Some data-correction and most data-management tasks are handled downstream.

TSG's first interaction with HyLogging data is to import it. This involves extracting the data streams, applying various corrections that are still required, synchronising the data streams, performing some QC checks, assembling useful ancillary info (tray geometry, depths, etc) and packaging it all up in a more familiar format (TSG's native format). At this point, the data are described as Level 1. Some processing decisions are best left to import time rather than measurement time and TSG's import procedure offers various options. The most obvious one is 'which raw data files should be grouped together and treated as a single entity?' (in other words, 'which trays constitute a drillhole?'), but there are other options concerning general downsampling and image correction.

Quality control (QC)

The HyLogging operating software provides a certain amount of QC feedback and TSG does more QC checks during import. Automated QC is a noble aspiration, but it only goes so far. Many QC decisions are subjective and some problems may arise that aren't recognised by any implemented checks. A good solution is to accompany the automated QC results with a comprehensive view of the data, so that a human can make the final call.

TSG's approach is to automate the most fundamental QC checks completely and to allow the user to set thresholds for some others. TSG's import can fail outright on clear QC failures. If the import works, TSG assembles a class scalar that shows any detected QC issues and displays it, along with mineral-identification (TSA) results and imagery, in the Tray screen (**Figure 3**). The user can form a reasonably good opinion of the data quality from this view and rescan the tray if it appears compromised. The objective is to ensure good quality data before the tray is removed from the HyLogger's table.

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2 The version of TSG used by the NTGS for HyLogger-3 data is TSG-HotCore. There are other versions for other applications – see: www.thespectralgeologist.com.
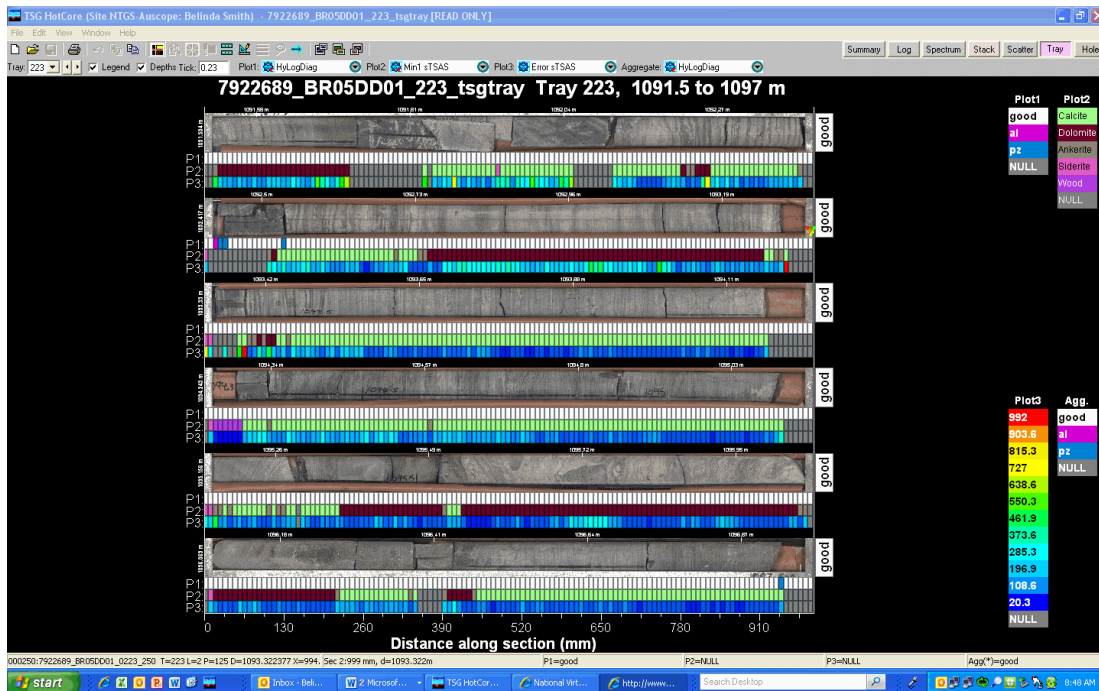
Figure 3. Data Output (Screen View) of TSG for one tray. Plot 1 shows HyLogger Diagnostic (QC) errors; Plot 2 shows the mineralogy of the dominant mineral from the SWIR spectrometer; Plot 3 shows the mineralogical modelling error returned by the TSA algorithm.

TSG QC

No matter how good QC checking is, it is of limited use, unless done as soon as possible after data acquisition. TSG-QC is like a TSG-Viewer that can do one extra thing – it can import one tray's worth of raw data. Each new HyLogger comes equipped with TSG-QC, which runs alongside the HyLogging operating software (the user might have to set it up). As soon as the operating software has completed measurements of a core tray, it sends TSG-QC a message and TSG-QC imports the data. Importing of data is usually complete by the time the HyLogger has reached the 'home' position (say within 30 seconds) and the operator can assess quality before unloading the tray.

Under certain conditions, TSG-QC's pre-digested data can be merged together quickly by a new import function in TSG-Core. This operation is far quicker than importing the raw data from scratch.

TSG and TSG TIR files

Once the raw HyLogger data are imported into TSG format they form a new "package" of files, whether at the core tray or final drill-hole level. The VNIR-SWIR (HyLogger-2 only) and the TIR data (included in the HyLogger-3) form two separate "packages" of files. When both are present each knows about the existence of the other and can be viewed together or separately in the TSG-HotCore software. NTGS' first implementation of the NVCL used a HyLogger-2 instrument that only had VNIR/SWIR data streams. For this data the TSG-Core software was used. With the upgrade to HyLogger-3 status TSG-HotCore or TSG-Viewer are now required.

A TSG package of data files for the VNIR-SWIR and its imagery data streams comprise the following files:

File name	Purpose
8418293_DD84G13_tsg.bip	Main file containing VNIR/SWIR spectra and scalar data. The prefix includes the drillhole identification name/number.
8418293_DD84G13_tsg.cal	Calibration data file
8418293_DD84G13_tsg.ini	TSG's initialisation file that records all screen layouts and parameters
8418293_DD84G13_tsg.tdl	Depth logging back-up file
8418293_DD84G13_tsg.tsg	TSG master control file (shows the TSG logo in subdirectories)
8418293_DD84G13_tsg_cras.bip	Linescan camera data file
8418293_DD84G13_tsg_hires.dat	Laser profilometer data file

For the thermal infrared (TIR) data from a HyLogger-3 a second package of data comprises the following files:

File name	Purpose
8418293_DD84G13_tsg_tir.bip	Main file containing TIR spectra and TIR related scalar data.
8418293_DD84G13_tsg_tir.cal	TIR calibration data file
8418293_DD84G13_tsg_tir.ini	TSG's initialisation file that records all screen layouts and parameters for the TIR data set.
8418293_DD84G13_tsg_tir.tsg	TSG master control file (shows the TSG logo in subdirectories)

The laser profilometer, depth logging and imagery files found in the first VNIR/SWIR package are shared between the two linked datasets.

The number of samples in a VNIR/SWIR package and its companion TIR package will be same as they come from a single HyLogging collection.

Conclusion

HyLogging is a method to bring objectivity and consistency to drill core logging, and to permit visualisation of mineralogy (which is often hard to determine with the naked eye). The outcomes are a variety of graphic and image logs (**Figures 4**, **5** and **6**) that depict this mineralogy and help geologists consider and question the processes that may have created the observed mineralogy and mineral assemblages. These processes may be primary, diagenetic, weathering, metamorphic or a variety of polyphase alterations. It is not a panacea! Outputs may be exported into other geoscience and mining software packages.
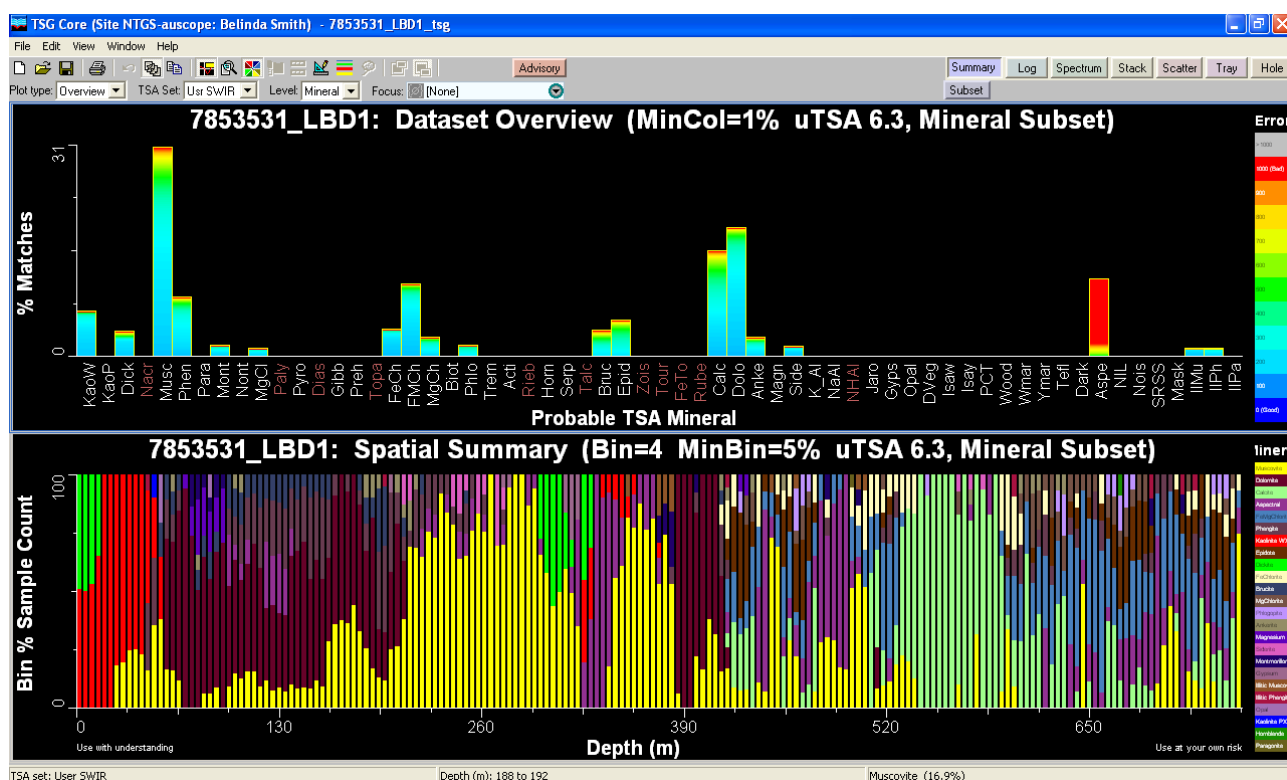

Figure 4. Example of data output formats from TSG software. Dataset overview and spatial summary of a drillhole. Dataset overview has the percentage of dataset samples that contain that mineral. Spatial summary shows the distribution of minerals for each 8m interval going down hole. Different domains of mineralogy can be delineated that reflect lithology and/or alteration changes.
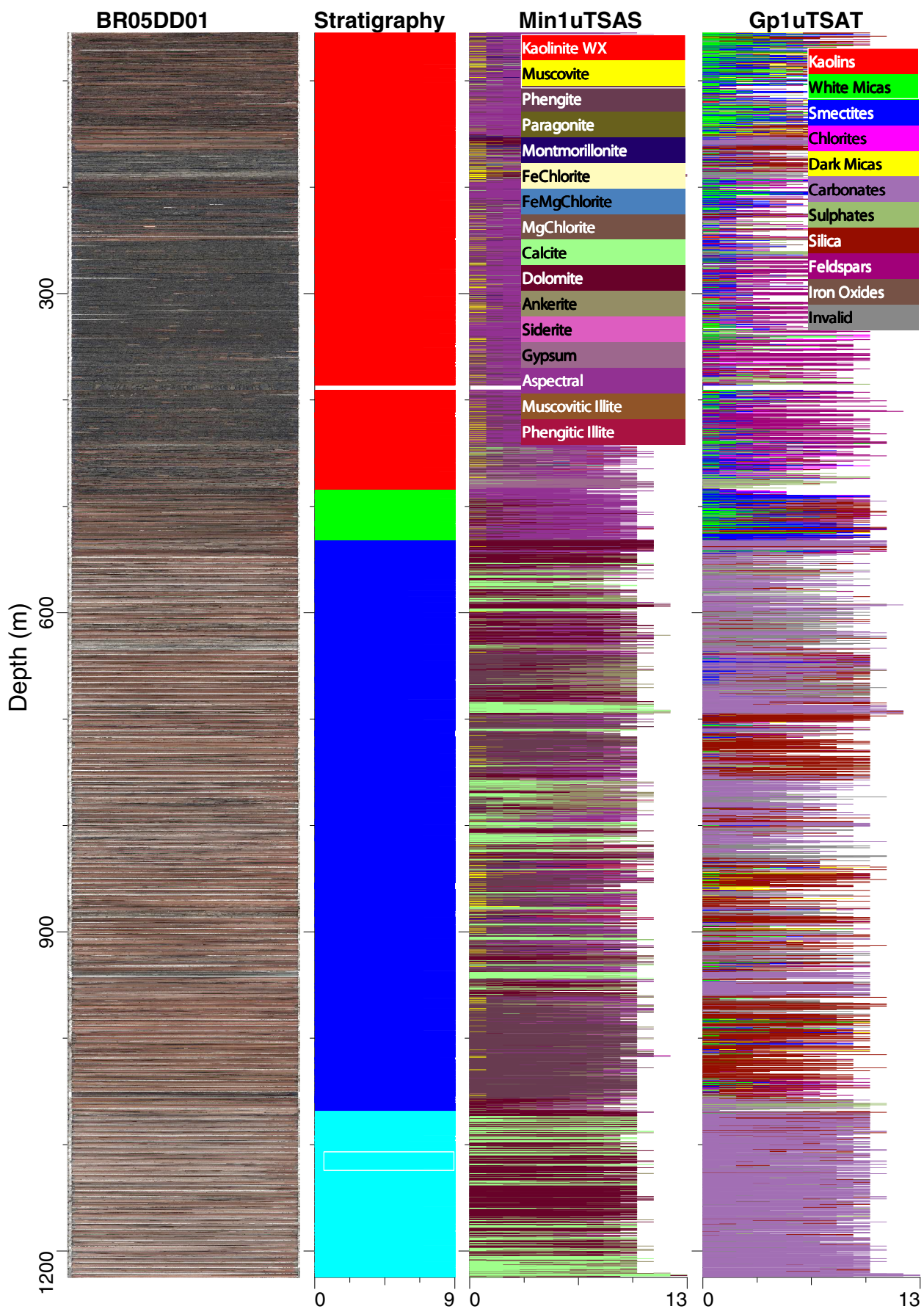
Figure 5. Example of data output formats from TSG software. Hole summary screen. The Hole Summary gives an overview of the dataset, using imagery and logged geology plotted with mineralogy. Columns (from left to right) show a hole mosaic image; logged stratigraphy; the legend for logged stratigraphy; Min1 uTAS (dominant mineral assemblage); Group mineral in TIR (Gp1 uTSAT).
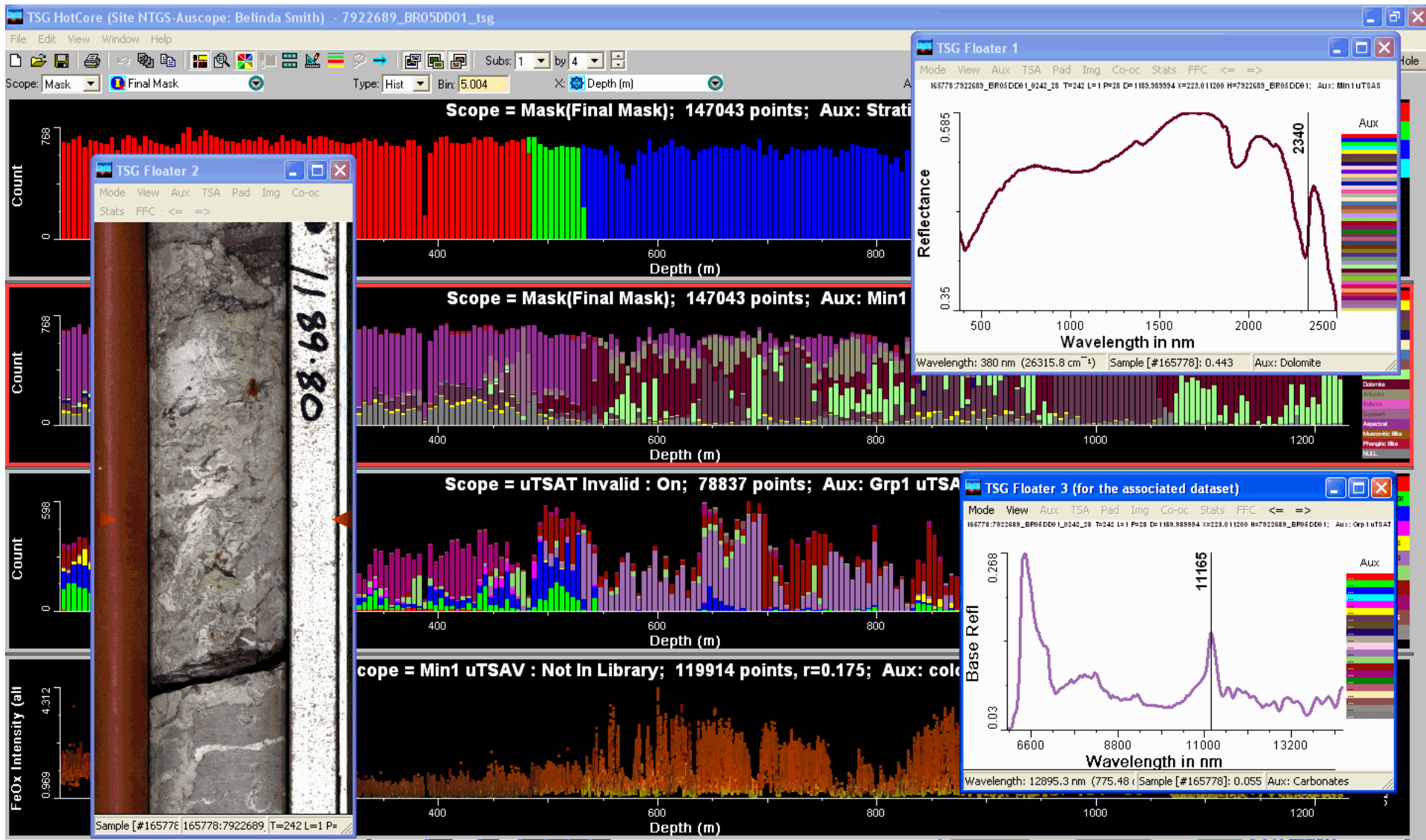
Figure 6. Example of data output formats from TSG software. Background screen shows histograms of data downhole (from left to right). The three insets are "floater" screens which can display spectra (SWIR in Floater 1); TIR (in Floater 3) or core imagery (Floater 2). The floater screens are liked to display variable data from the same depth simultaneously.

Glossary of acronyms and technical terms commonly used in HyLogging spectroscopy.

Albedo	Normally applied to the mean broadband brightness of a spectrum over a specified wavelength range. A white or altered sample will commonly have a high albedo, whereas a graphitic rock will have a very low albedo.
AlOH	Aluminium hydroxide
CCD	Charge coupled device
FTIR	Fourier transform infrared spectrometer
HgCdTe	Mercury Cadmium Telluride used in infrared detectors
HQ	Shorthand for hull quotient (a type of background corrected spectrum)
IFOV	Instantaneous field of view (of an instrument)
InSb	Indium antimonide – used in infrared detectors
LN_2	Liquid nitrogen
MCT	Mercury Cadmium Telluride used in infrared detectors
MgOH	Magnesium hydroxide
MIR	Mid infrared
nm	Nanometre, being one billionth of a metre. A HyLogger-2 operates between 380 and 2500 nm). A HyLogger-3 adds the 6000-14500 nm range.
Ref	Abbreviation for reflectance
QC	Quality Control; a series of validations to ensure data output quality
SNR	Signal-to-noise ratio
SRSS	Standardised residual sum of squares (TSA's measure of mineral identification error). Low SRSS values are more reliable than high ones. The current default 'bad' threshold is 1000.
SWIR	Shortwave infrared (light). Nominally covering the range 1000–2500 nm)
TSA	'The Spectral Assistant' – a CSIRO trademarked algorithm that uses training libraries of pure spectra to model an unknown spectrum to a single mineral or to identify a mixture of two minerals. Part of the TSG software package.
TSG	'The Spectral Geologist' – CSIRO-developed specialist processing software, designed for analysis of field or laboratory spectrometer data.
TIR	Thermal infrared (light). Nominally covering the range (6000-14500 nm)
um or μm	Micrometre (formerly micron), being one millionth of a metre. A HyLogger 2 operates between 0.38 and 2.5 micrometres. A HyLogger-3 adds the 6.0–14.5 micrometer range
Vis	Visible (light). The human eye is nominally sensitive between 390 and 750 nm
VNIR	Visible near infrared (light). Nominally covering the range 380–1000 nm.
wvl	Abbreviation for wavelength, found in TSG scalar names
λ	Lambda – Often used as a symbol for wavelength of light.