Geological and structural controls on hydrothermal alteration and W-Mo mineralization in the Sisson deposit, New Brunswick

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Abstract: The Sisson deposit is a Late Devonian, structurally-controlled, intrusion-related W-Mo deposit located in west-central New Brunswick. Resources are estimated at 383 Mt grading 0.067 % WO_3 and 0.021 % Mo (measured/indicated) and 178 Mt grading 0.051 % WO_3 and 0.021 % Mo (inferred). Host rocks to Sisson include quartz diorite and gabbro phases (432 Ma; U-Pb on titanite) of the Howard Peak intrusion on the west, which are in fault contact across the vertical, north-trending Sisson shear zone with north-northwest-striking, steeply east-dipping metavolcanic and metasedimentary rocks of the Cambrian to Ordovician Tetagouche and Miramichi Groups on the east. Re-Os dates of ca. 378 Ma on molybdenite overlap U-Pb dates on zircon from narrow granite dykes within the deposit, which are likely related to the Late Devonian Nashwaak Granite batholith located immediately northwest of the deposit. The deposit is cut by narrow, undeformed, barren granite porphyry dykes dated at ca. 364 Ma (U-Pb on zircon).

The Sisson deposit obliquely straddles the Sisson shear zone. Hydrothermal activity comprises: (1) early, weakly to unmineralized amphibole veinlets with albite alteration envelopes and small, erratically-distributed zones of biotite±pyrite alteration; (2) quartz- scheelite veinlets with biotite envelopes; (3) quartz-molybdenite±scheelite veinlets with sericite envelopes; (4) mostly late but possibly long-lived, larger and more continuous, polymetallic quartz-shear veins with broad sericite envelopes and associated sulphide-rich veinlets, which also introduced minor Cu, Bi, Sb, As, Pb and Zn to the deposit; and (5) rare endoskarn with scheelite mineralization of uncertain timing in narrow granite dykes intersected only at depths of >400 metres. Alteration is mostly restricted to the envelopes which enclose veinlets. Scheelite mineralization occurs primarily in quartz veinlets and their alteration envelopes, molybdenite is restricted to quartz veinlets, and minor ferberitic wolframite, mostly replaced by scheelite, occurs in some quartz-scheelite veinlets and in most quartz-shear veins.

Veins throughout the deposit form a sheeted array with consistent northwest strike and steep to moderate southwest dips. The nature and geometry of the vein sets are most compatible with formation during crustal extension, which was synchronous with sinistral, syn-hydrothermal displacement across the north-trending Sisson shear zone. The structural plumbing system focused ascent of W-mineralizing fluids from intrusions at depth, the presence of which is indicated by syn-hydrothermal granite dykes within the deposit. Precipitation of W and Mo mineralization resulted from chemical interactions between hydrothermal fluids and wall rock at a low fluid to rock ratio, and from changes in sulphur and oxygen fugacity.

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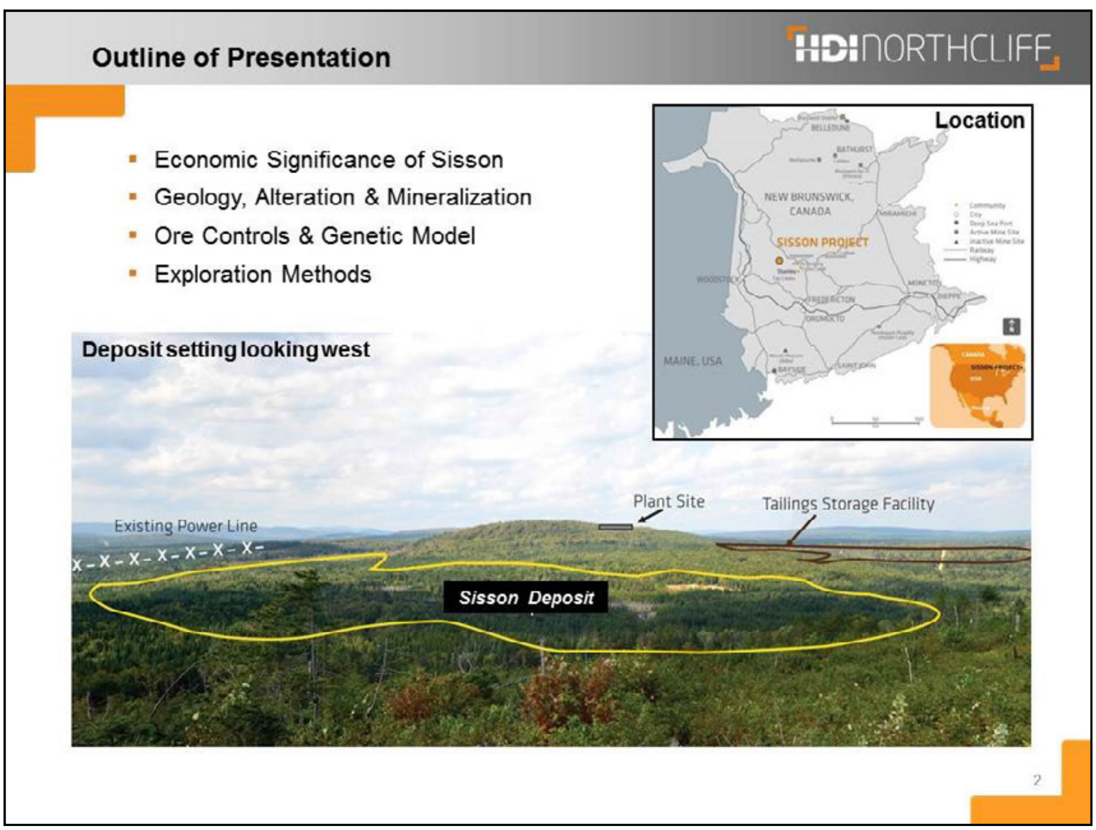
HDI NORTHCLIFF
The Sisson W-Mo Project, New Brunswick:
Deposit Geology, Ore Controls & Exploration Methods
Authors: Lang, J.; Duncan, R.; Lentz, D.; Zhang, W.;
Bustard, A.; McFarlane, C.; Thorne, K


Outline of Presentation
HDI NORTHCLIFF
▪ Economic Significance of Sisson
▪ Geology, Alteration & Mineralization
▪ Ore Controls & Genetic Model
▪ Exploration Methods
Location
NEW BRUNSWICK, CANADA
SISSON PROJECT
MAINE, USA
Deposit setting looking west
Existing Power Line
Plant Site
Tailings Storage Facility
Sisson Deposit
2

Reserves & Mining Plan

HDI NORTHCLIFF

Sisson is one of the most significant tungsten reserves outside of China
(2013 Northcliff Feasibility Study)

Sisson Deposit 43-101 Mineral Reserves (January 2013 at $8.83/tonne NSR cutoff[1])

Category	Cut-Off Grade (NSR $/t)	Tonnes (Mt)	NSR ($/t)	WO_3 (%)	Mo (%)	Tungsten (WO3) (million MTUs)	Contained Mo (Mlb)
Proven	8.83	105.4	25.48	0.069	0.023	7.3	53.0
Probable	8.83	228.9	23.54	0.065	0.020	14.9	101.7
Total	8.83	334.4	24.15	0.066	0.021	22.2	154.8

[1]Contained within Ultimate Pit Limit. Metal Prices: WO_3–US$350/metric tonne unit (mtu), Mo–US$15/lb; Assumed Concentrator Recoveries: WO_3–variable with feed grade, Mo–82%; APT Plant Recovery of WO_3–97%; USD$:CDN$0.9:1; NSR=(WO_3% * NSP WO_3*Recovery WO_3*22.046)+(Mo%*NSP Mo Recovery Mo*22.046); Net Smelter Price (NSP) WO_3=CDN$17.46/lb; Mo=CDN$14.50/lb.

FEASIBILITY PRODUCTION PLAN:

- Mine life of 27 years
- Average annual production:
  - 557,000 MTU/yr WO_3 (MTU = 10 kg contained WO_3)
  - 4.1M lbs/yr Mo
- First ammonium paratungstate (APT) plant in Canada

3

Sisson Project History

HDI NORTHCLIFF

1978 – 1984
- Discovery by Kidd Creek Mines (TexasGulf)

2004 – 2009
- Geodex Minerals advanced and largely delineated the deposit

2010 – Present
- Northcliff Resources
  - Initial JV with Geodex in late 2010
  - Acquired 100% of project in June 2012
  - Positive feasibility study completed January 2013
  - EIA submitted mid-2013

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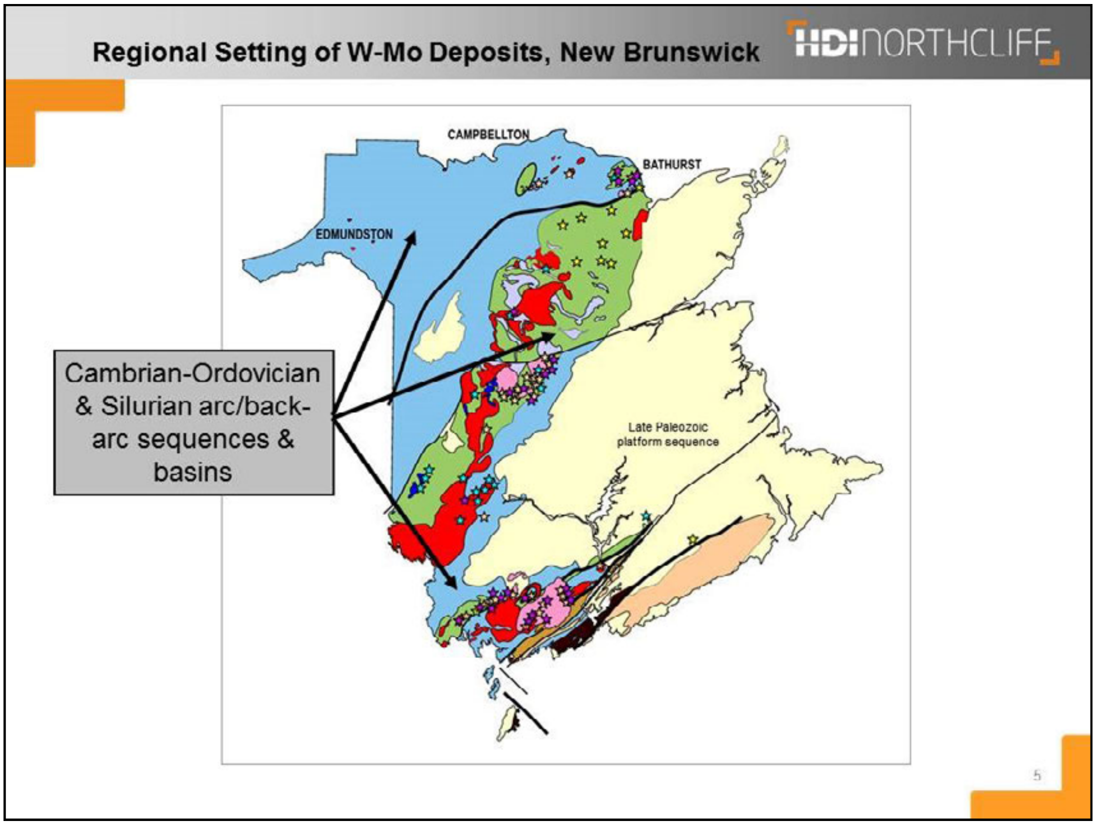
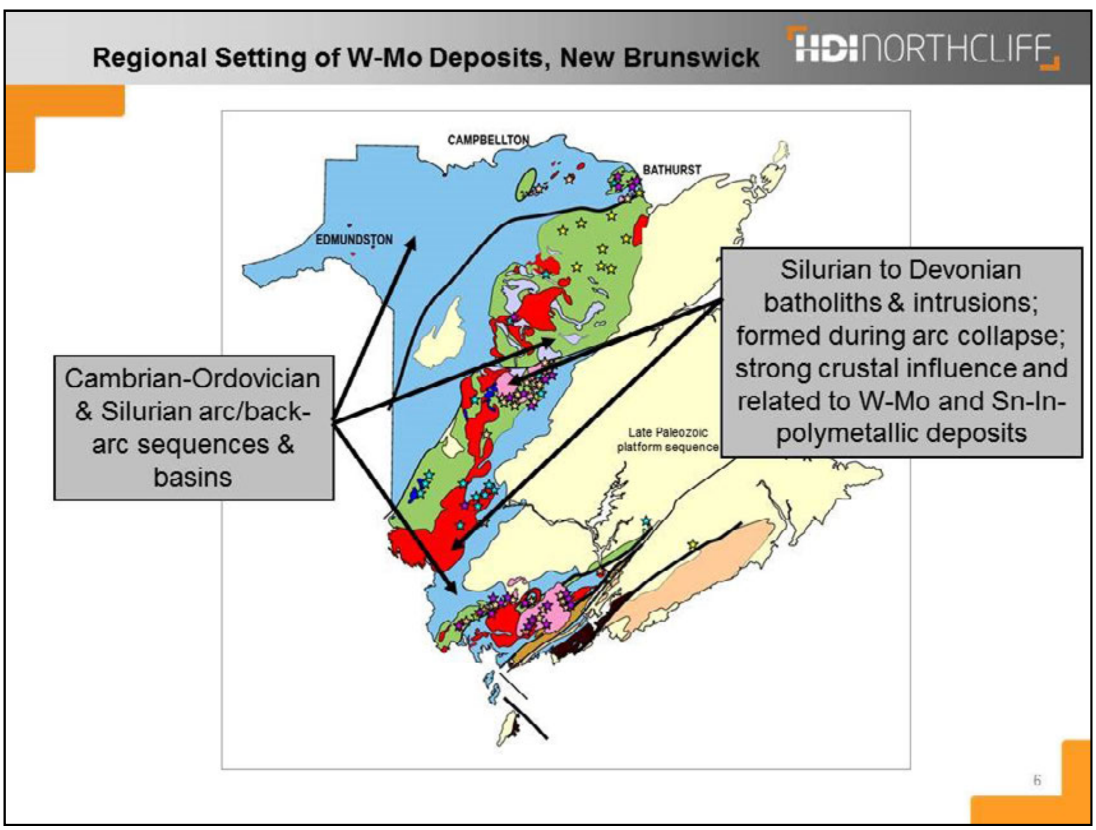
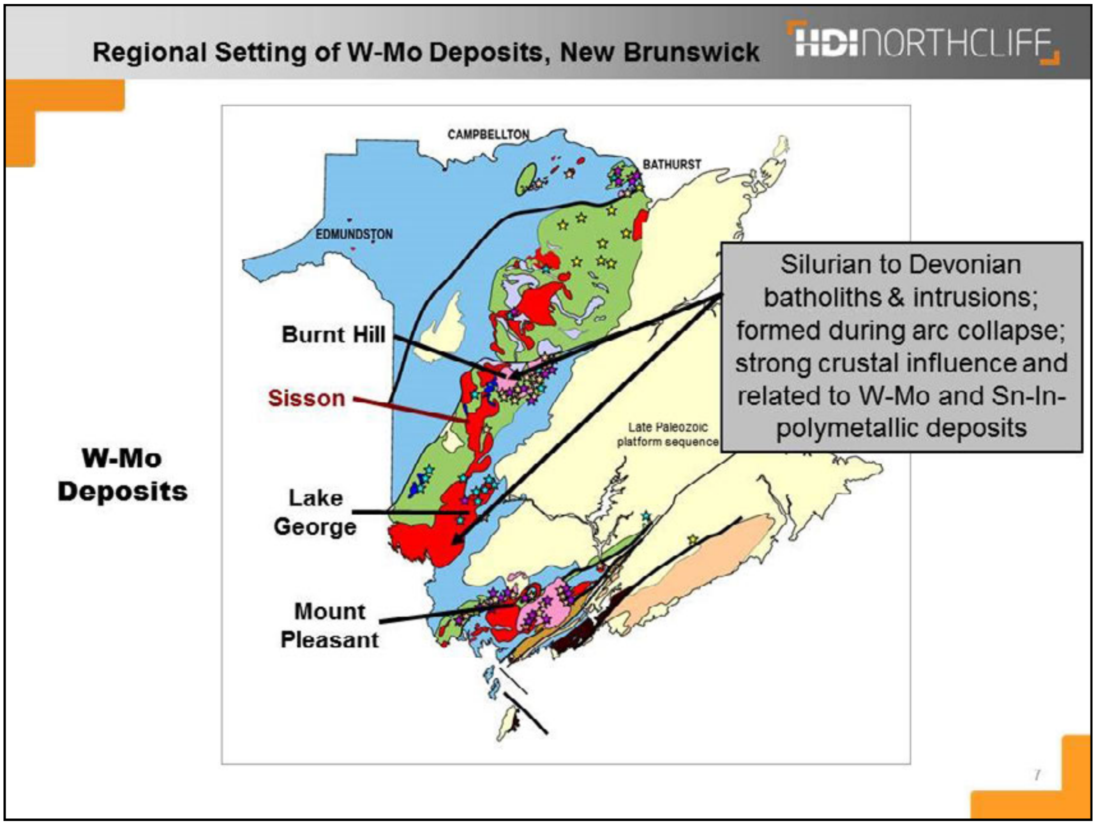
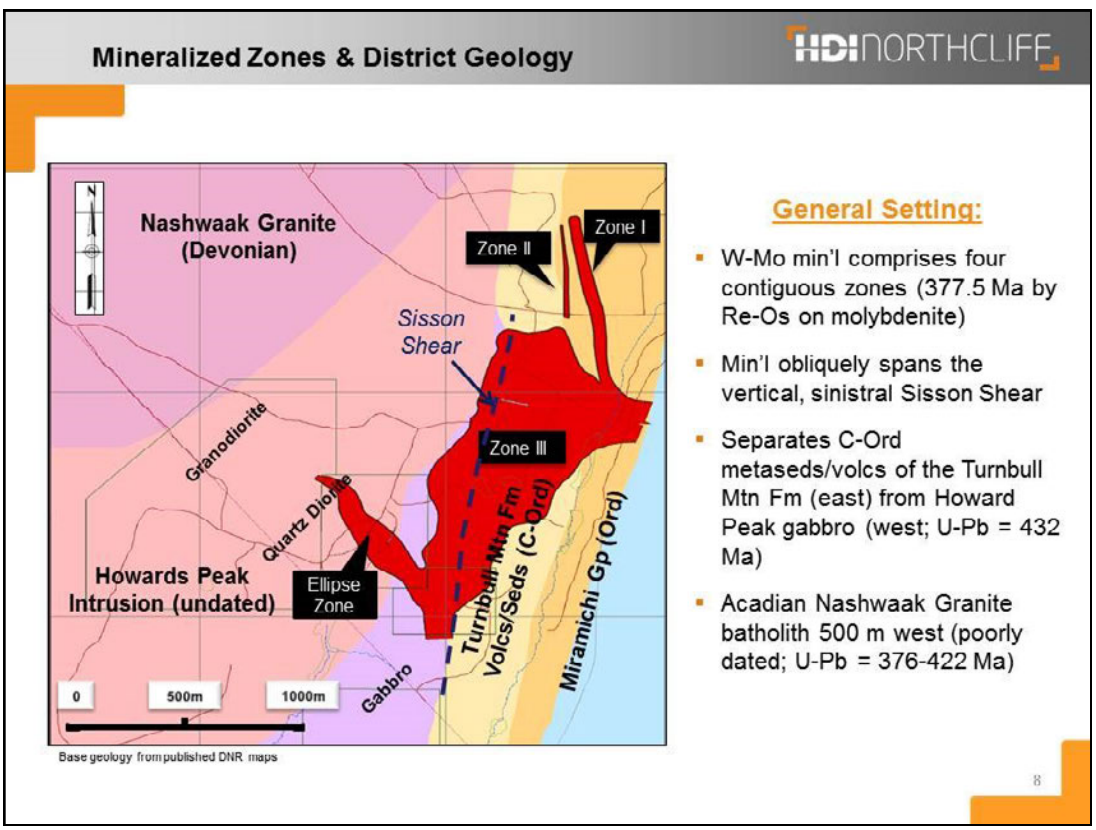
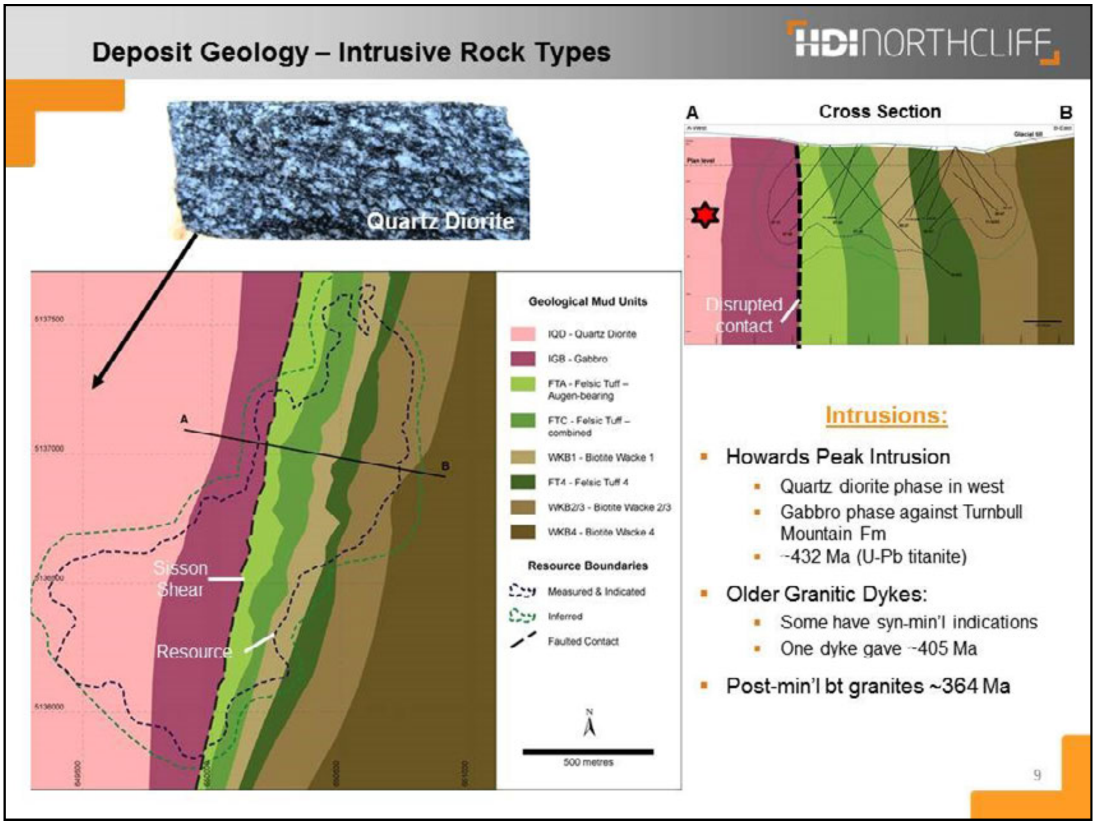

Regional Setting of W-Mo Deposits, New Brunswick
CAMPBELLTON
BATHURST
EDMUNDSTON
Cambrian-Ordovician & Silurian arc/back-arc sequences & basins
Late Paleozoic platform sequence
5

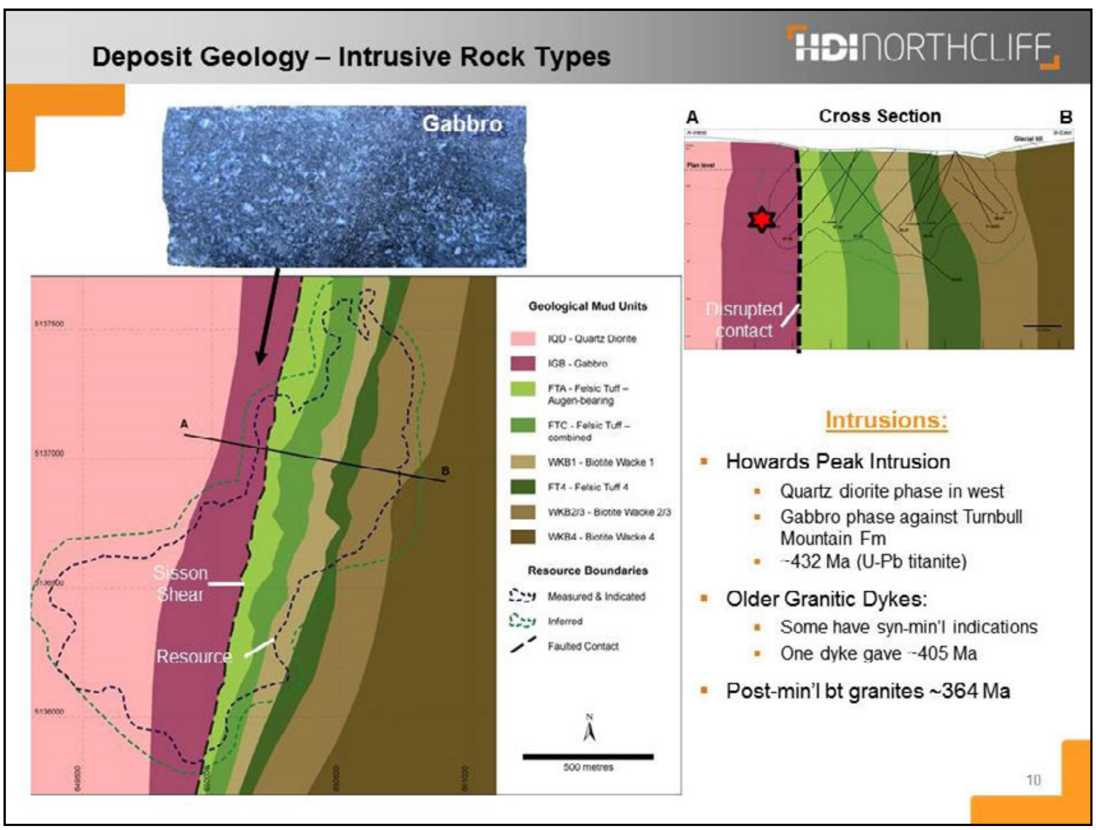

Regional Setting of W-Mo Deposits, New Brunswick
CAMPBELLTON
BATHURST
EDMUNDSTON
Silurian to Devonian batholiths & intrusions; formed during arc collapse; strong crustal influence and related to W-Mo and Sn-In-polymetallic deposits
Cambrian-Ordovician & Silurian arc/back-arc sequences & basins
Late Paleozoic platform sequence
6


Regional Setting of W-Mo Deposits, New Brunswick
HDI NORTHCLIFF
CAMPBELLTON
BATHURST
EDMUNDSTON
Burnt Hill
Sisson
W-Mo Deposits
Lake George
Mount Pleasant
Late Paleozoic platform sequence
Silurian to Devonian batholiths & intrusions; formed during arc collapse; strong crustal influence and related to W-Mo and Sn-In-polymetallic deposits
7


Mineralized Zones & District Geology
HDI NORTHCLIFF
Nashwaak Granite (Devonian)
Zone II
Zone I
Sisson Shear
Granodiorite
Zone III
Quartz Diorite
Howards Peak Intrusion (undated)
Ellipse Zone
Turnbull Mtn Fm Volcs/Seds (C-Ord)
Miramichi Gp (Ord)
Gabbro
0
500m
1000m
Base geology from published DNR maps
General Setting:
W-Mo min'l comprises four contiguous zones (377.5 Ma by Re-Os on molybdenite)
Min'l obliquely spans the vertical, sinistral Sisson Shear
Separates C-Ord metaseds/volcs of the Turnbull Mtn Fm (east) from Howard Peak gabbro (west; U-Pb = 432 Ma)
Acadian Nashwaak Granite batholith 500 m west (poorly dated; U-Pb = 376-422 Ma)
8



Deposit Geology – Intrusive Rock Types
HDI NORTHCLIFF
Quartz Diorite
Cross Section
A
B
Disrupted contact
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
FTA - Felsic Tuff – Augen-bearing
FTC - Felsic Tuff – combined
WKB1 - Biotite Wacke 1
FT4 - Felsic Tuff 4
WKB2/3 - Biotite Wacke 2/3
WKB4 - Biotite Wacke 4
Resource Boundaries
Measured & Indicated
Inferred
Faulted Contact
500 metres
Sisson Shear
Resource
Intrusions:
Howards Peak Intrusion
Quartz diorite phase in west
Gabbro phase against Turnbull Mountain Fm
~432 Ma (U-Pb titanite)
Older Granitic Dykes:
Some have syn-min'l indications
One dyke gave ~405 Ma
Post-min'l bt granites ~364 Ma
9



Deposit Geology – Intrusive Rock Types
HDI NORTHCLIFF
Gabbro
Cross Section
A
B
Disrupted contact
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
FTA - Felsic Tuff – Augen-bearing
FTC - Felsic Tuff – combined
WKB1 - Biotite Wacke 1
FT4 - Felsic Tuff 4
WKB2/3 - Biotite Wacke 2/3
WKB4 - Biotite Wacke 4
Resource Boundaries
Measured & Indicated
Inferred
Faulted Contact
500 metres
Sisson Shear
Resource
Intrusions:
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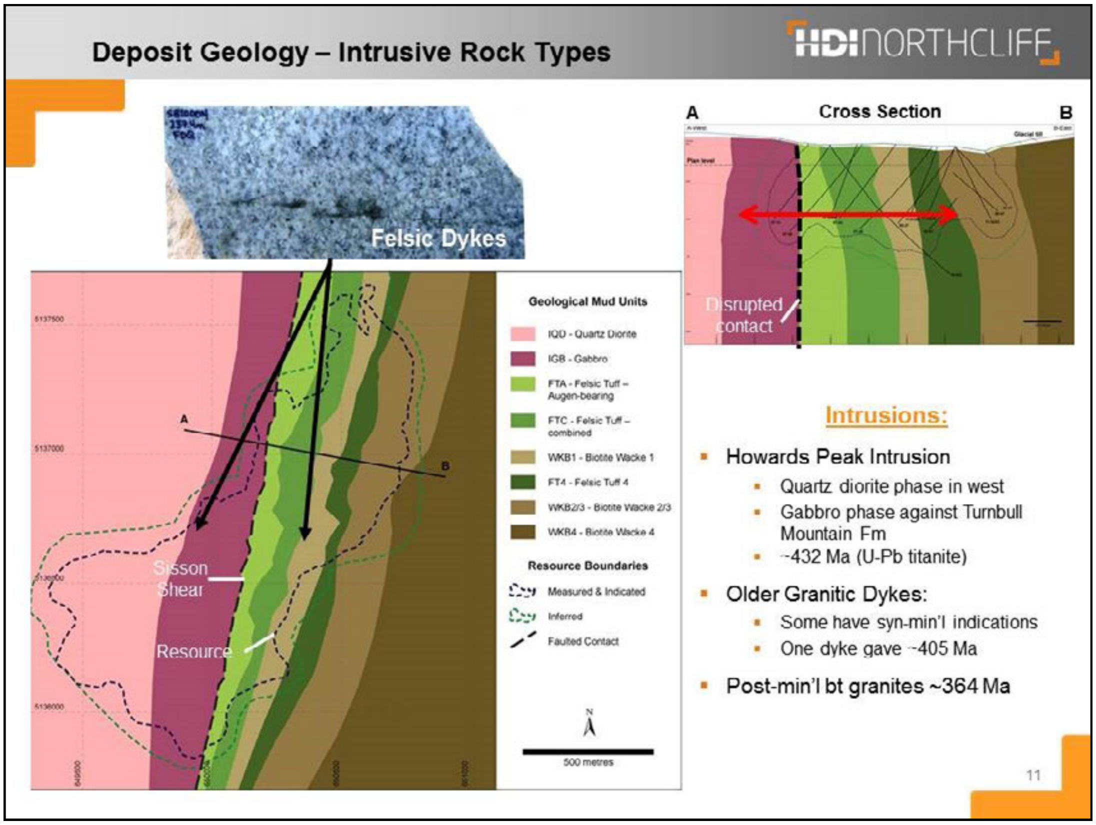
10


Deposit Geology – Intrusive Rock Types
HDI NORTHCLIFF
Felsic Dykes
Cross Section
A
B
Disrupted contact
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
FTA - Felsic Tuff – Augen-bearing
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Resource Boundaries
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Inferred
Faulted Contact
500 metres
Sisson Shear
Resource
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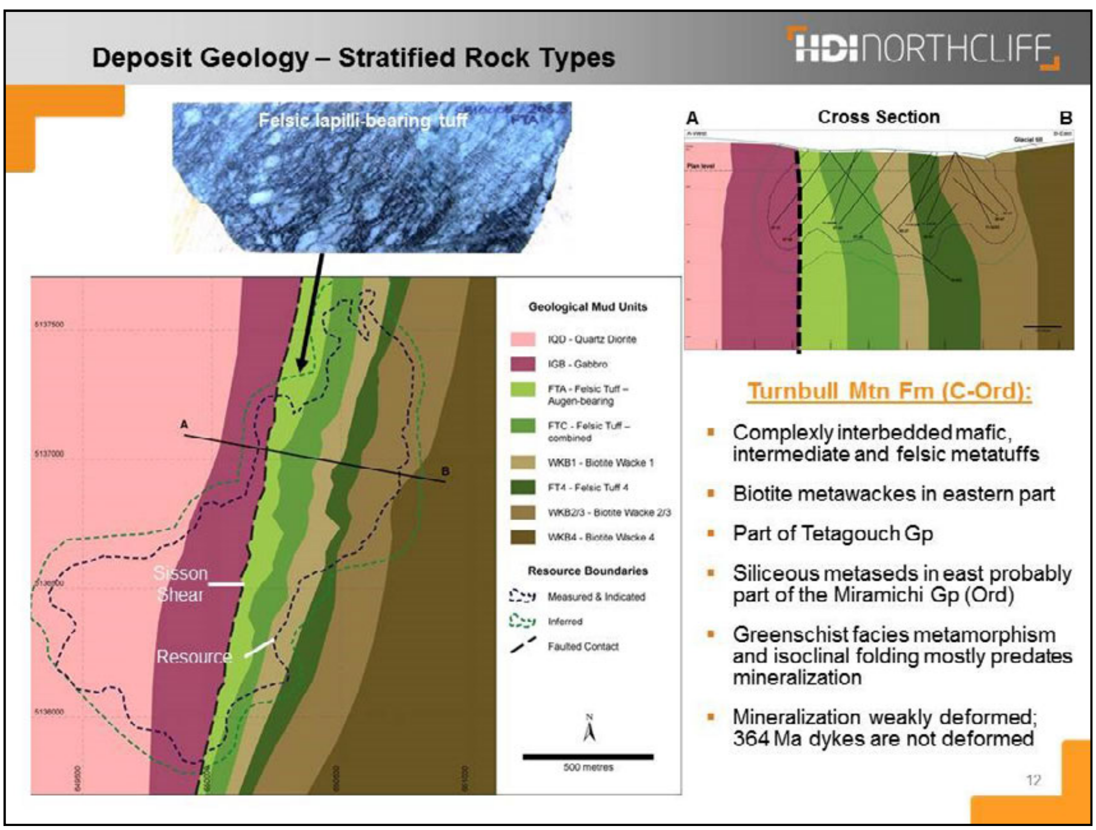
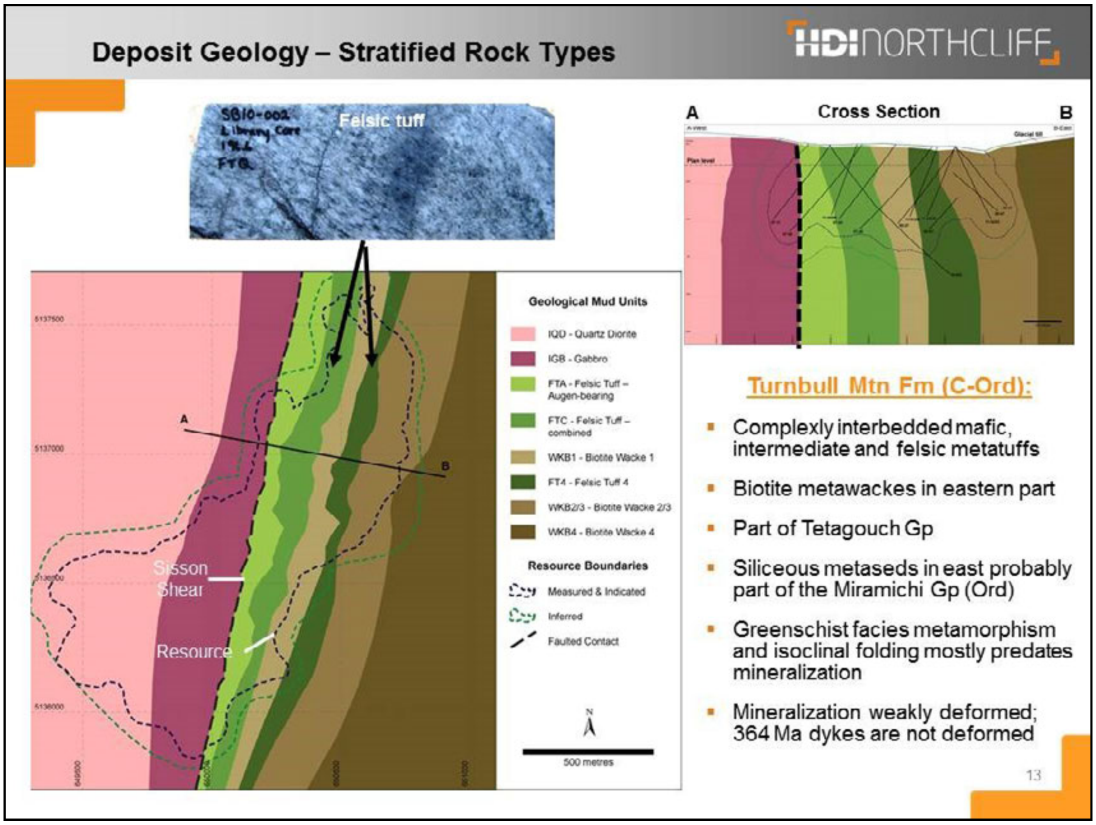

Deposit Geology – Stratified Rock Types
HDI NORTHCLIFF
Felsic lapilli-bearing tuff
Cross Section
A
B
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
FTA - Felsic Tuff – Augen-bearing
FTC - Felsic Tuff – combined
WKB1 - Biotite Wacke 1
FT4 - Felsic Tuff 4
WKB2/3 - Biotite Wacke 2/3
WKB4 - Biotite Wacke 4
Resource Boundaries
Measured & Indicated
Inferred
Faulted Contact
500 metres
Sisson Shear
Resource
Turnbull Mtn Fm (C-Ord):
Complexly interbedded mafic, intermediate and felsic metatuffs
Biotite metawackes in eastern part
Part of Tetagouch Gp
Siliceous metaseds in east probably part of the Miramichi Gp (Ord)
Greenschist facies metamorphism and isoclinal folding mostly predates mineralization
Mineralization weakly deformed; 364 Ma dykes are not deformed
12


Deposit Geology – Stratified Rock Types
HDI NORTHCLIFF
Felsic tuff
Cross Section
A
B
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
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Measured & Indicated
Inferred
Faulted Contact
Sisson Shear
Resource
500 metres
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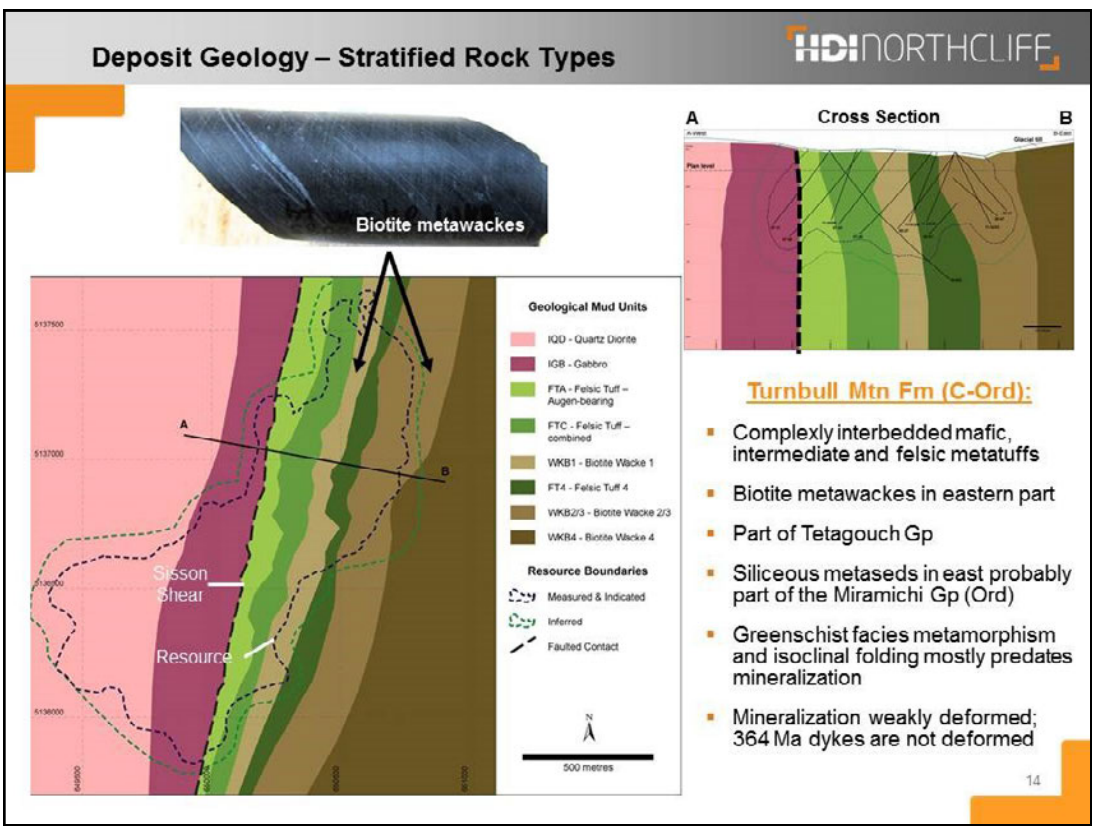
Deposit Geology – Stratified Rock Types
HDI NORTHCLIFF
Biotite metawackes
Cross Section
A
B
Geological Mud Units
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Resource Boundaries
Measured & Indicated
Inferred
Faulted Contact
Sisson Shear
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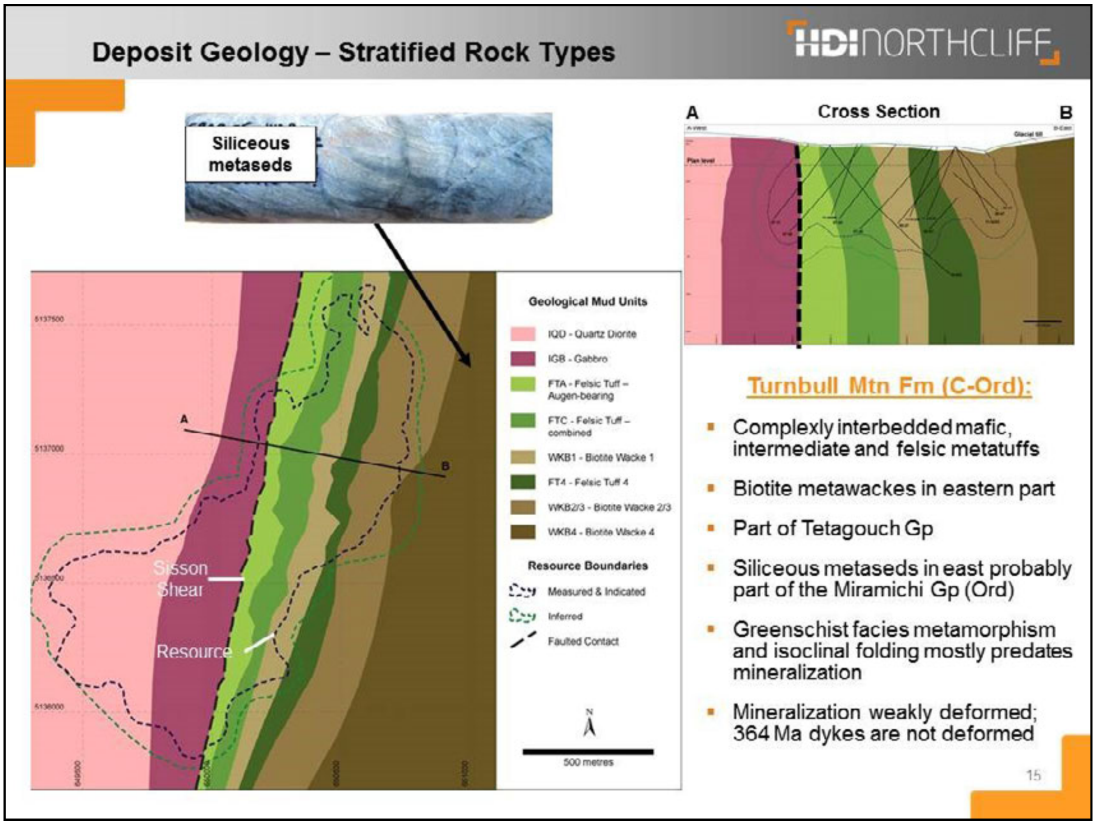
14


Deposit Geology – Stratified Rock Types
HDI NORTHCLIFF
Siliceous metaseds
Cross Section
A
B
Geological Mud Units
IQD - Quartz Diorite
IGB - Gabbro
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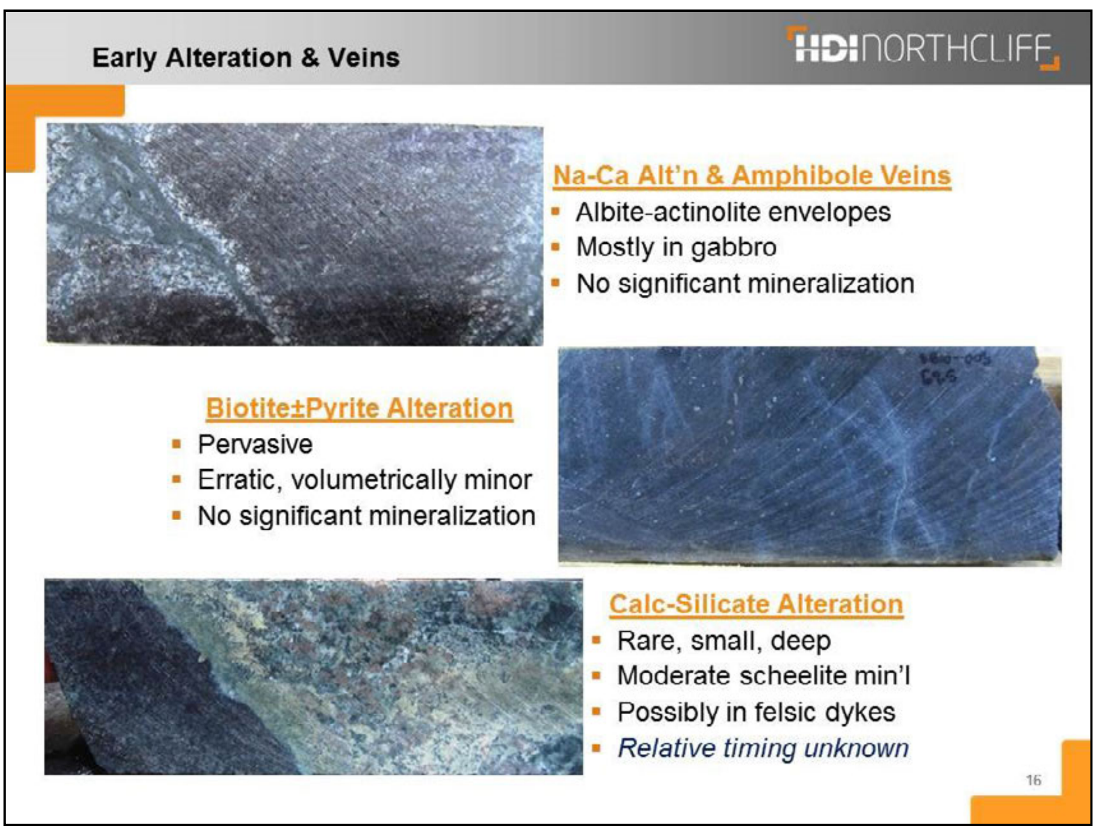
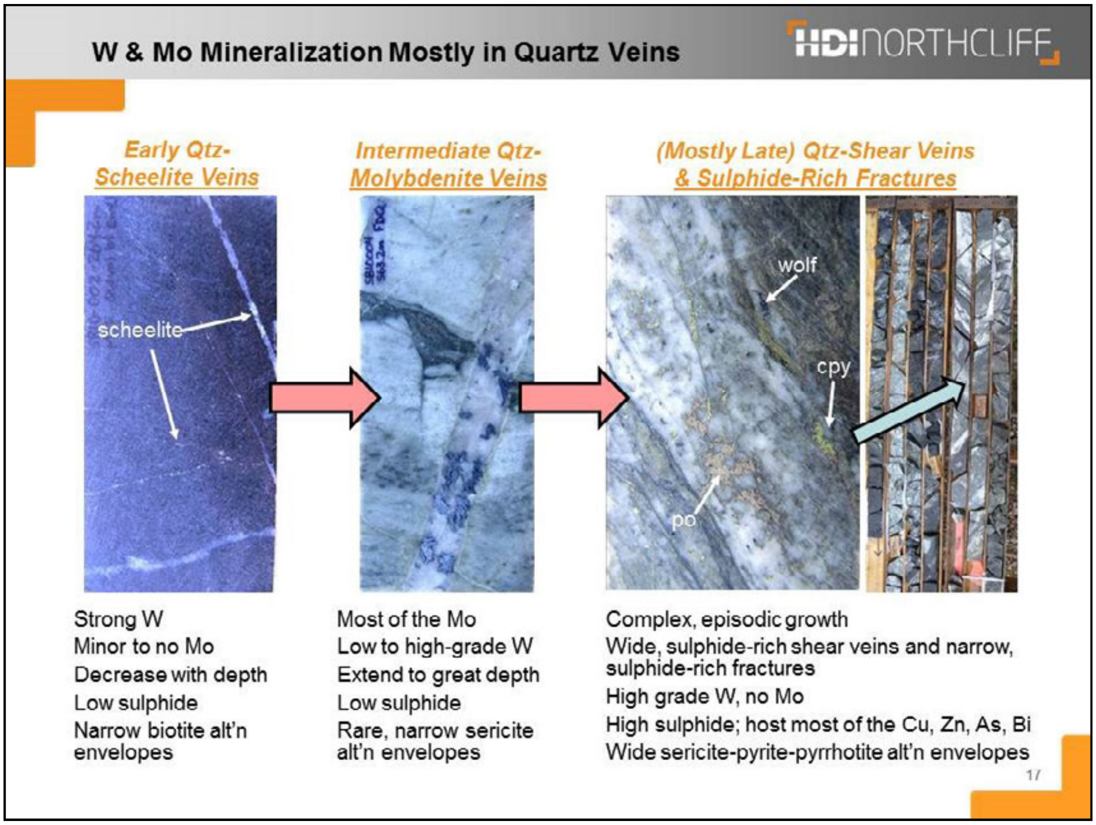
15


Early Alteration & Veins
HDI NORTHCLIFF
Na-Ca Alt'n & Amphibole Veins
Albite-actinolite envelopes
Mostly in gabbro
No significant mineralization
Biotite±Pyrite Alteration
Pervasive
Erratic, volumetrically minor
No significant mineralization
Calc-Silicate Alteration
Rare, small, deep
Moderate scheelite min'l
Possibly in felsic dykes
Relative timing unknown
16


W & Mo Mineralization Mostly in Quartz Veins
HDINORTHCLIFF
Early Qtz-Scheelite Veins
Intermediate Qtz-Molybdenite Veins
(Mostly Late) Qtz-Shear Veins & Sulphide-Rich Fractures
scheelite
wolf
cpy
po
Strong W
Minor to no Mo
Decrease with depth
Low sulphide
Narrow biotite alt'n envelopes
Most of the Mo
Low to high-grade W
Extend to great depth
Low sulphide
Rare, narrow sericite alt'n envelopes
Complex, episodic growth
Wide, sulphide-rich shear veins and narrow, sulphide-rich fractures
High grade W, no Mo
High sulphide; host most of the Cu, Zn, As, Bi
Wide sericite-pyrite-pyrrhotite alt'n envelopes
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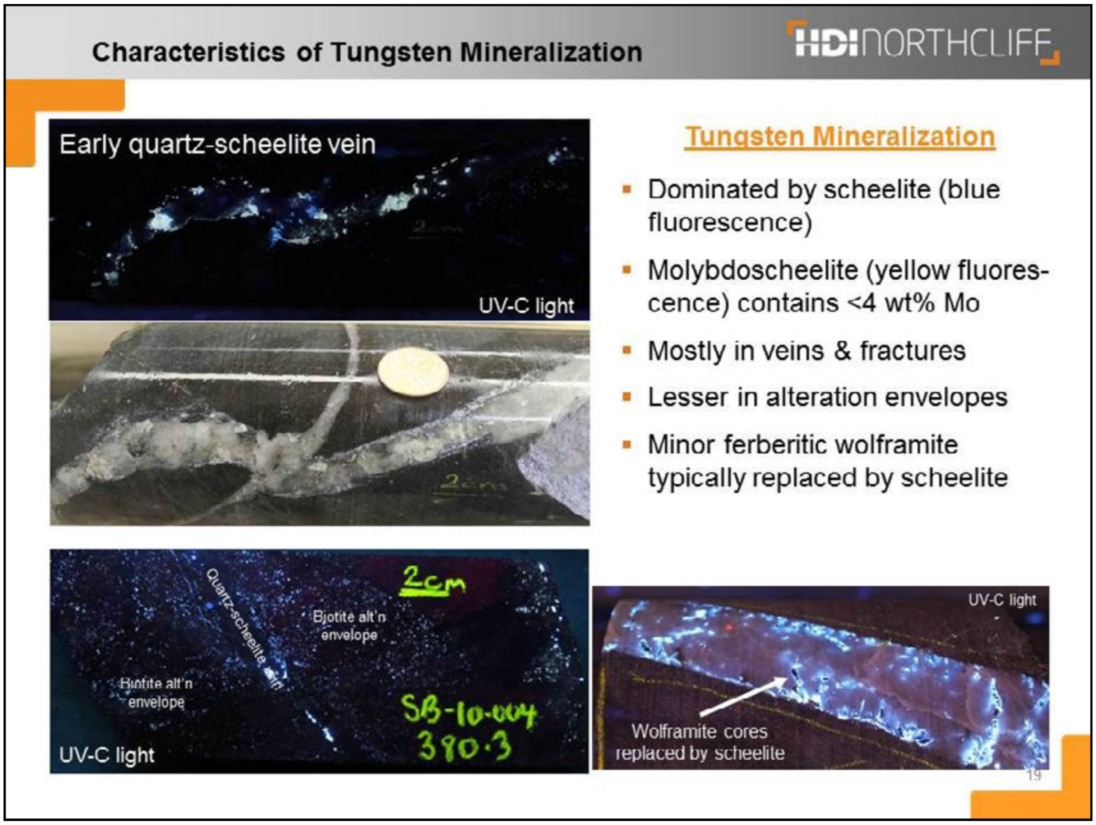
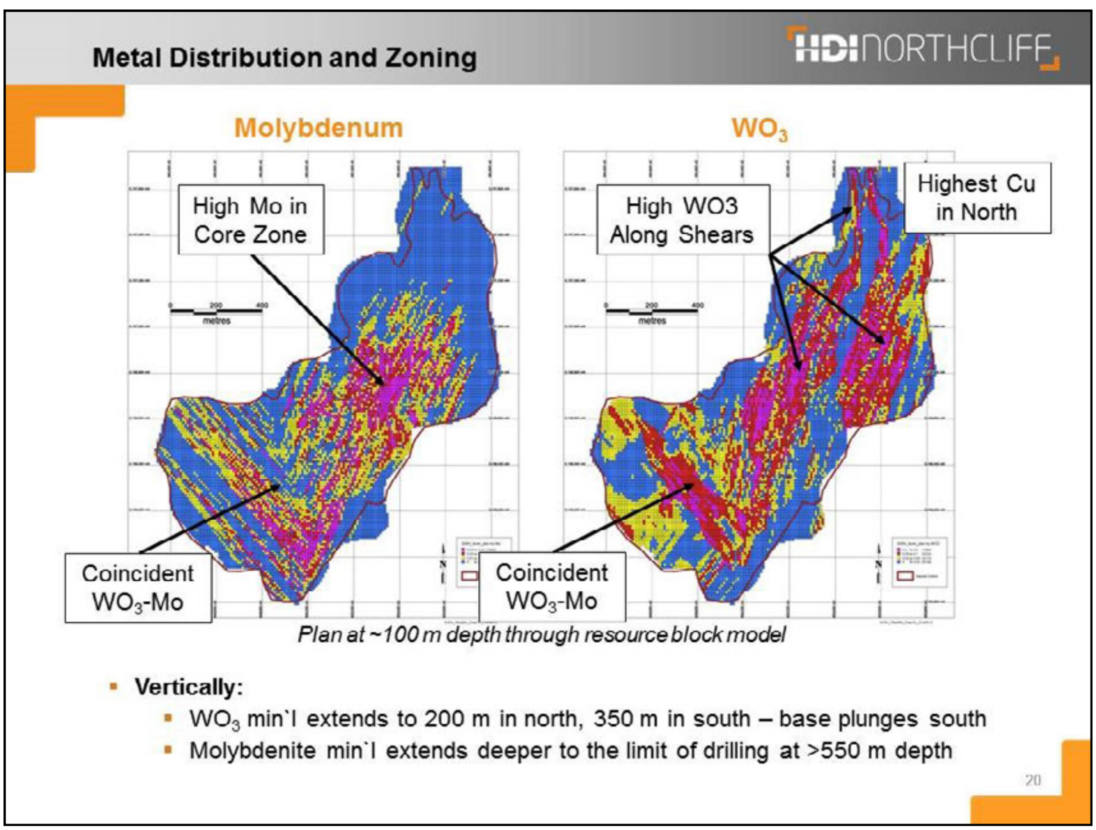
Veins, Alteration & Mineralization
HDINORTHCLIFF
Vein density is low & domains between veinlets are nearly unaltered
Hydrothermal system was weak or largely confined to fractures/veinlets
18


Characteristics of Tungsten Mineralization
HDINORTHCLIFF
Early quartz-scheelite vein
UV-C light
Tungsten Mineralization
Dominated by scheelite (blue fluorescence)
Molybdoscheelite (yellow fluorescence) contains <4 wt% Mo
Mostly in veins & fractures
Lesser in alteration envelopes
Minor ferberitic wolframite typically replaced by scheelite
2cm
Quartz-scheelite vein
Biotite alt'n envelope
Biotite alt'n envelope
SB-10-004
380.3
UV-C light
UV-C light
Wolframite cores replaced by scheelite
19


Metal Distribution and Zoning
HDINORTHCLIFF
Molybdenum
WO_3
High Mo in Core Zone
High WO3 Along Shears
Highest Cu in North
Coincident WO_3-Mo
Coincident WO_3-Mo
Plan at ~100 m depth through resource block model
Vertically:
WO_3 min`l extends to 200 m in north, 350 m in south – base plunges south
Molybdenite min`l extends deeper to the limit of drilling at >550 m depth
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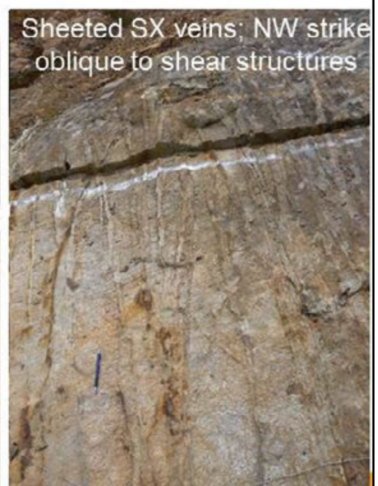
Vein Structural Relationships

HDI NORTHCLIFF

- ***Larger shear veins*** – NNE-striking, ~vertical, sinistral movement
- ***Sheeted veinlet arrays*** – NW-striking, SW-dipping, mineralized fractures and extension veins



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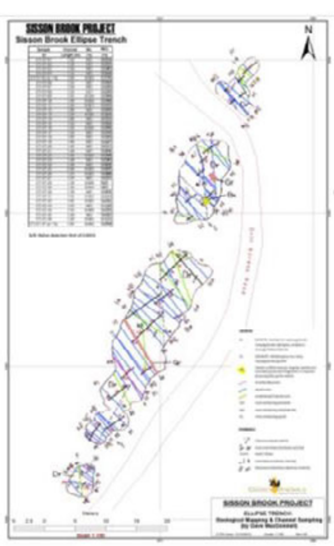
Sheeted Vein Arrays Are Ubiquitous

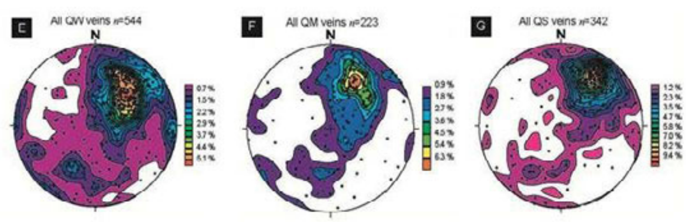
HDI NORTHCLIFF

Veins in Ellipse Zone Trench



Veins in Oriented Drill Core

Qtz-Scheelite Veins | Qtz-Molybdenite Veins | Qtz-Shear Veins



Vein Orientations:

- Strong preferred NW strike for all vein types
- Steep dips, mostly to the SW
- A few wide veins strike N in mapped trenches
- Sheeted vein array likely located between larger sinistral shear zones

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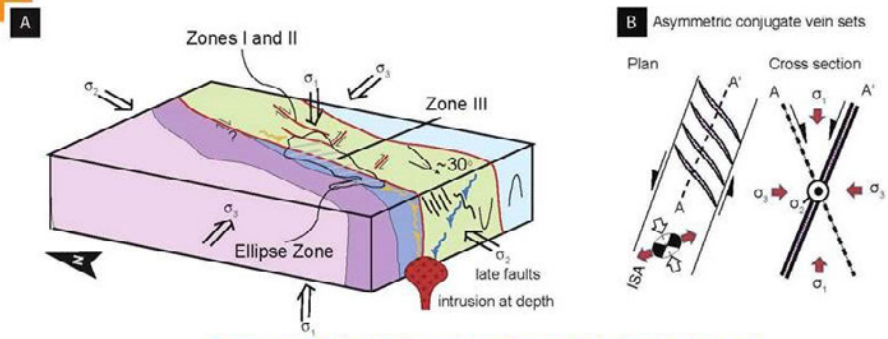
Magmatic-Hydrothermal-Structural Model

HDI NORTHCLIFF



Structural Control & Provisional Genetic Model:

- **Timing.** Late Acadian trans-tensional stress
- **Plumbing System.** Vertical, NNE sinistral faults (wide QS veins) which control intervening sheeted vein sets (QW, QM, sulphidic fractures)
- **Fluids.** Magmatic origin supported by $\delta^{18}O$ in vein quartz and rare endoskarn in granite dykes
- **Source.** Probably a late, marginal phase related to the Nashwaak Granite at depth, controlled by same structural regime
- **Fluid Flux.** Low or confined, indicated by weak alteration & low vein density
- **Conditions.** Fluid inclusions (Nast, 1985) indicate WO_3 min'l at 370-430°C and 500 bars.

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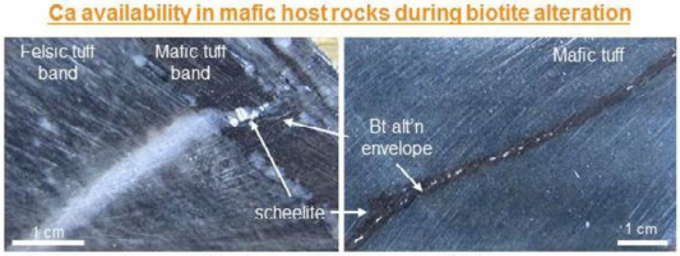
Controls on Scheelite Precipitation

HDI NORTHCLIFF

- Fluid – wall rock interaction probably critical:
  - Alteration mostly confined to vein envelopes – low or very confined fluid flux.
  - **Fluid-mineral reactions and local chemical component availability (Ca, Ti).**
  - Destabilized $HKWO_3$ complexes = scheelite ppt'n
  - Other proposals: prograde versus retrograde temperature regimes, fluid mixing, changes in fS_2
  - More study required

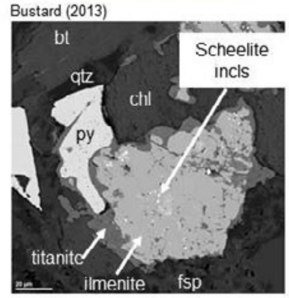
Ca availability in mafic host rocks during biotite alteration



- Major control proposed by Nast and Williams-Jones (1991)
- See this W-mafic (Ca) relationship at many scales at Sisson

Reactions involving Ti-bearing minerals

Bustard (2013)



Simplified reactions:

$Hbl + Plag + Ti\,(aq) + 2HKWO_3 = Bt + 2Scheelite + Ilmenite$

&

$Bt + Ilmenite + Ca + S = Titanite + Py + Chl$

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Methods for Exploration Through Glacial Cover

HDI NORTHCLIFF

- Potential tools for exploration through glacial cover at Sisson:
  - Soil gas hydrocarbon analysis (proprietary method of Actlabs)
  - Geochemical patterns of W and other metals in basal tills
  - Heavy indicator minerals, such as scheelite, in basal tills

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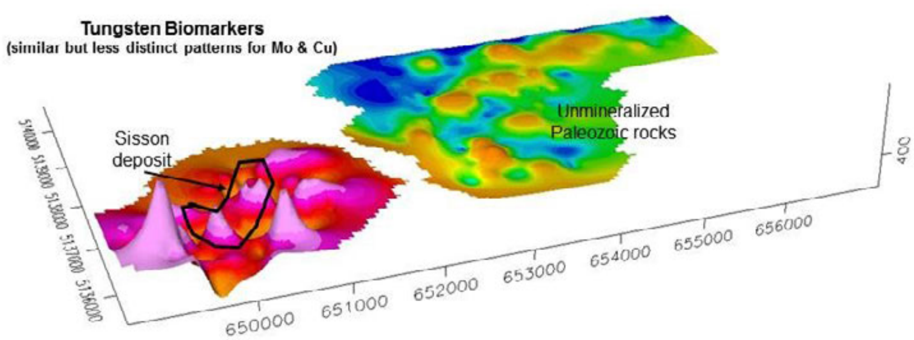
Exploration – Soil Gas Hydrocarbon (SGH) Surveys

HDI NORTHCLIFF



- Soil gas hydrocarbon analysis (proprietary method from Actlabs)
- Based on groups of hydrocarbons (biomarkers) released by dying microbes which had interacted with ore minerals at depth
- Used basic soil sampling methods
- In a blind study SGH successfully highlighted Sisson using W, Mo & Cu biomarkers
- SGH also recognized internal metal zoning between W, Mo & Cu

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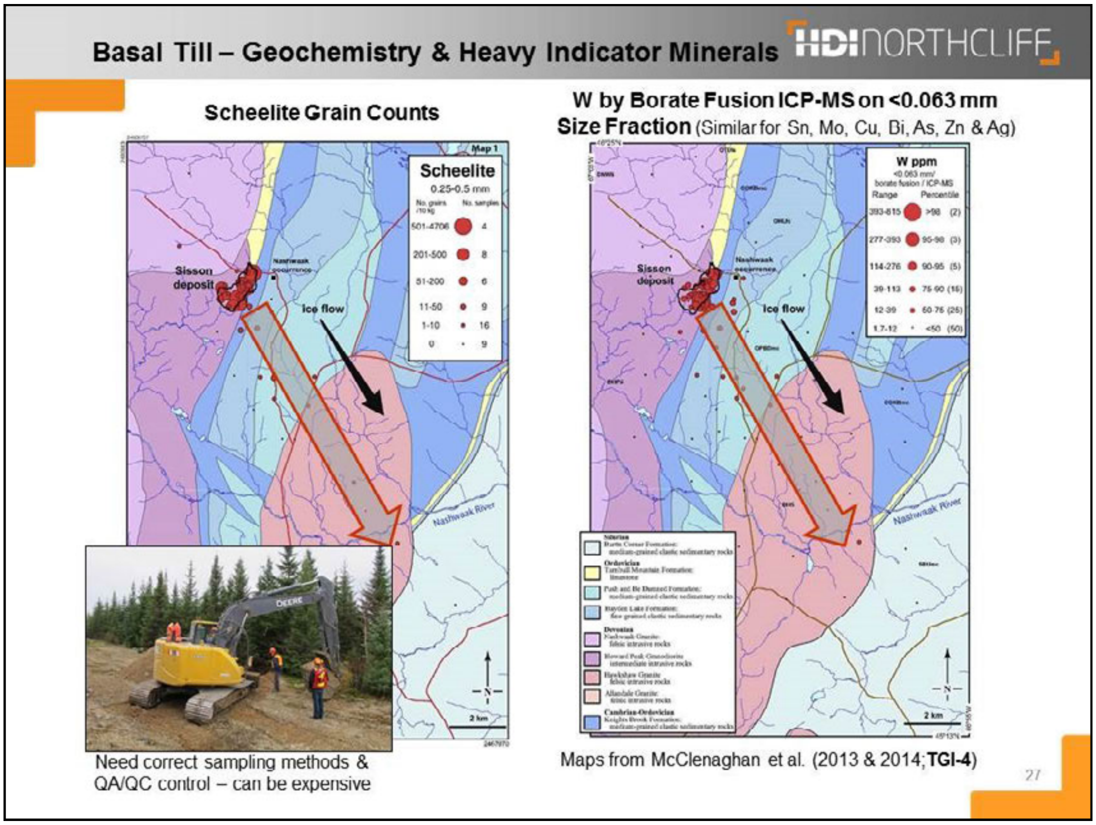

Key Points

- Sisson is a very large, intrusion-related, structurally-controlled, bulk-tonnage W-Mo deposit.
- Mineralization occurs in a sheeted vein array controlled by larger, well-mineralized, sinistral shear zones active in the Late Devonian.
- The fracture network focused upflow of fluids from an underlying felsic intrusion represented within the deposit by granitic dykes.
- Intrusions associated with min'l were plausibly Late Devonian, marginal phases of the nearby Nashwaak Granite batholith.
- Geochemical and heavy indicator mineral surveys in basal till are excellent regional exploration tools.
- Soil gas hydrocarbon surveys may further focus local exploration.

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