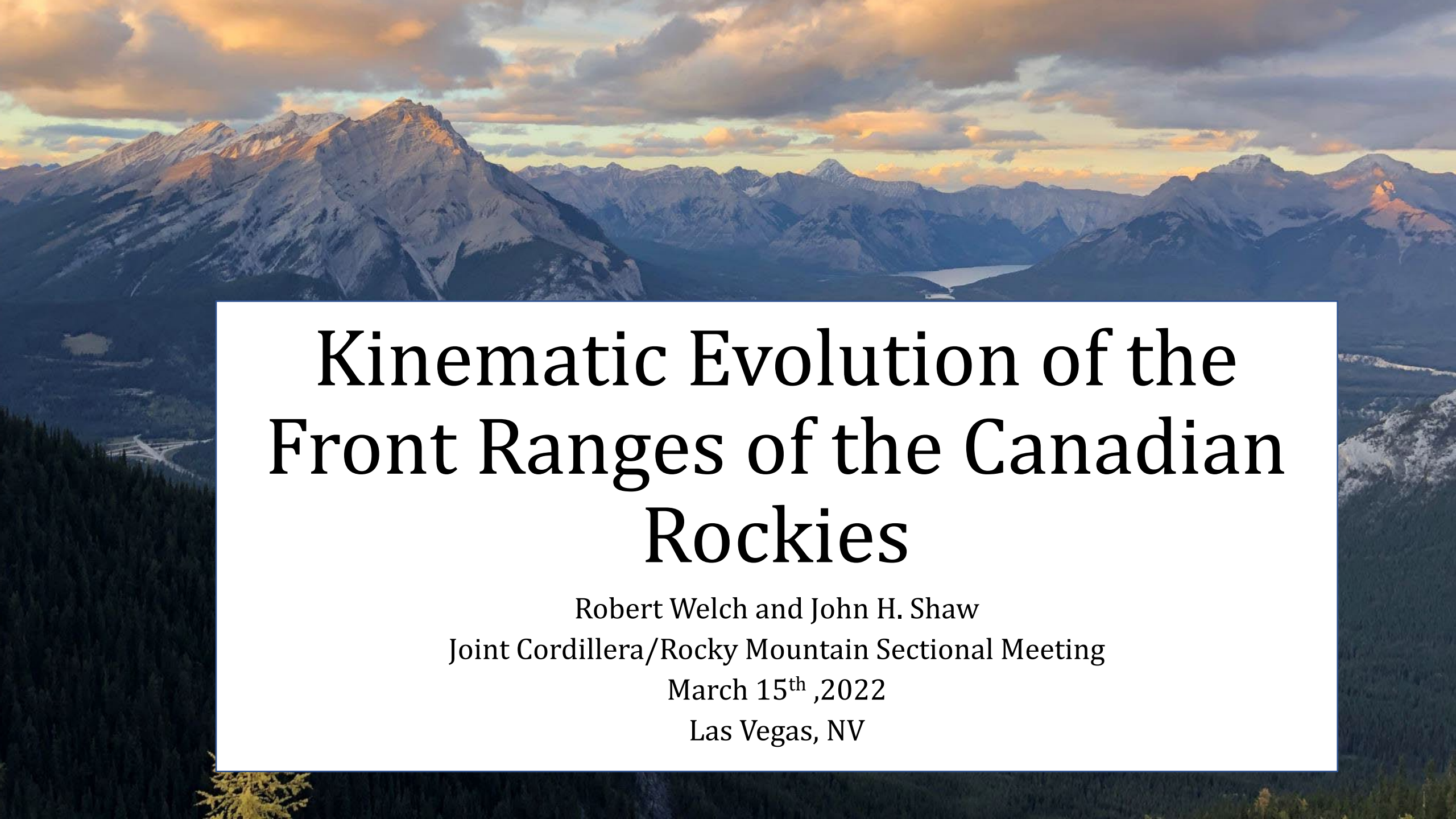
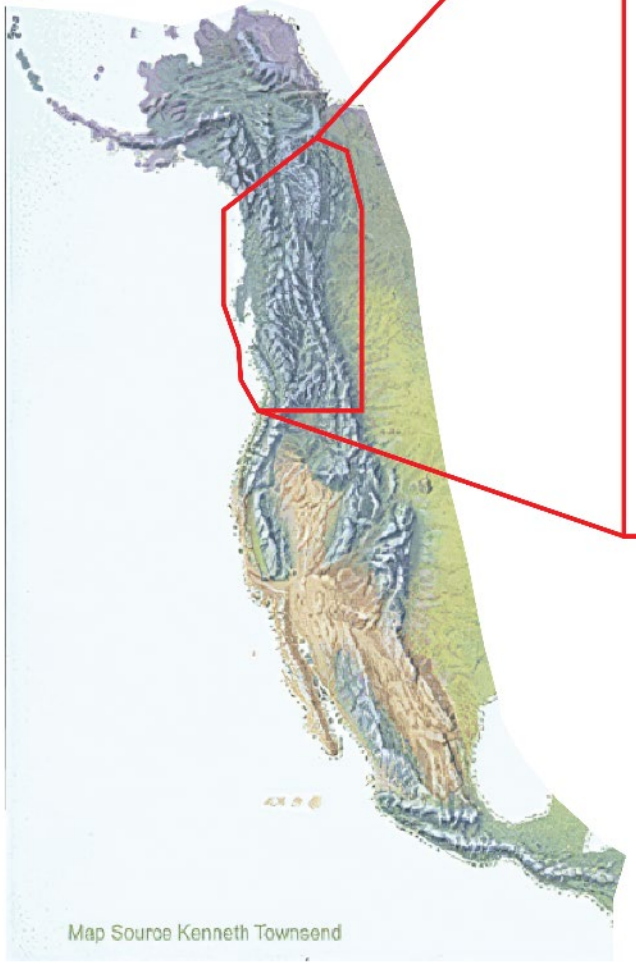


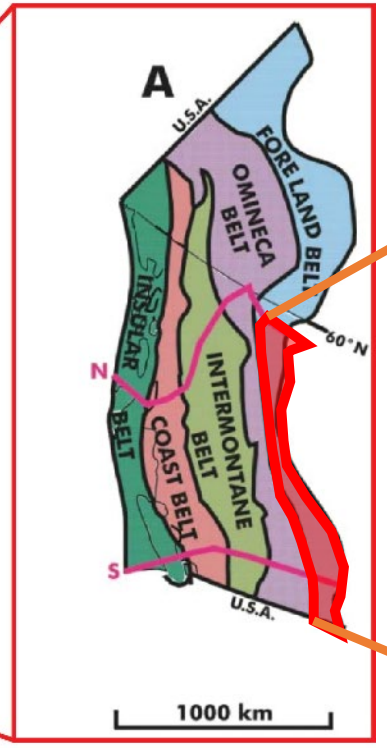
Kinematic Evolution of the Front Ranges of the Canadian Rockies

Robert Welch and John H. Shaw

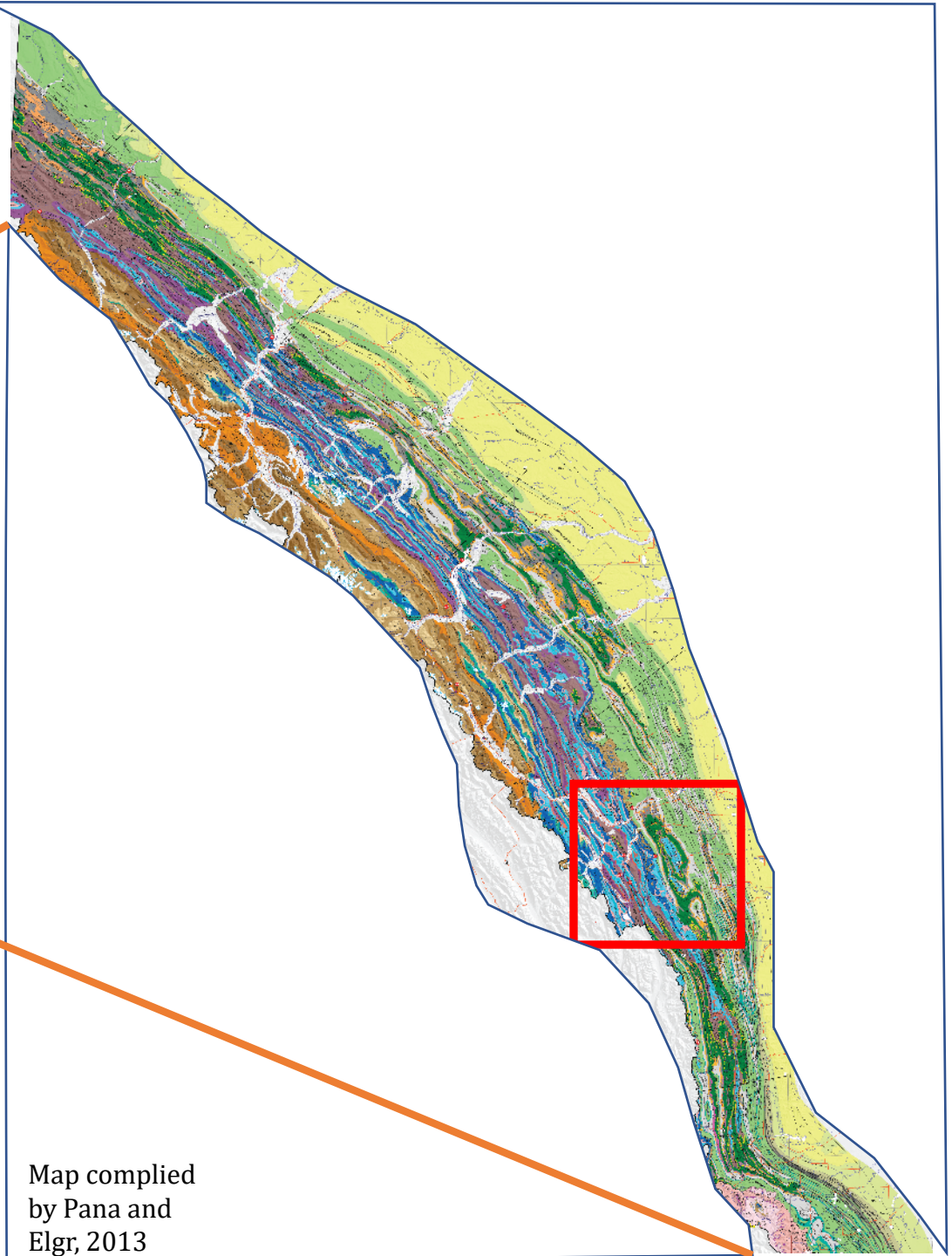
Joint Cordillera/Rocky Mountain Sectional Meeting
March 15th ,2022
Las Vegas, NV

The Front Ranges of the Canadian Rockies



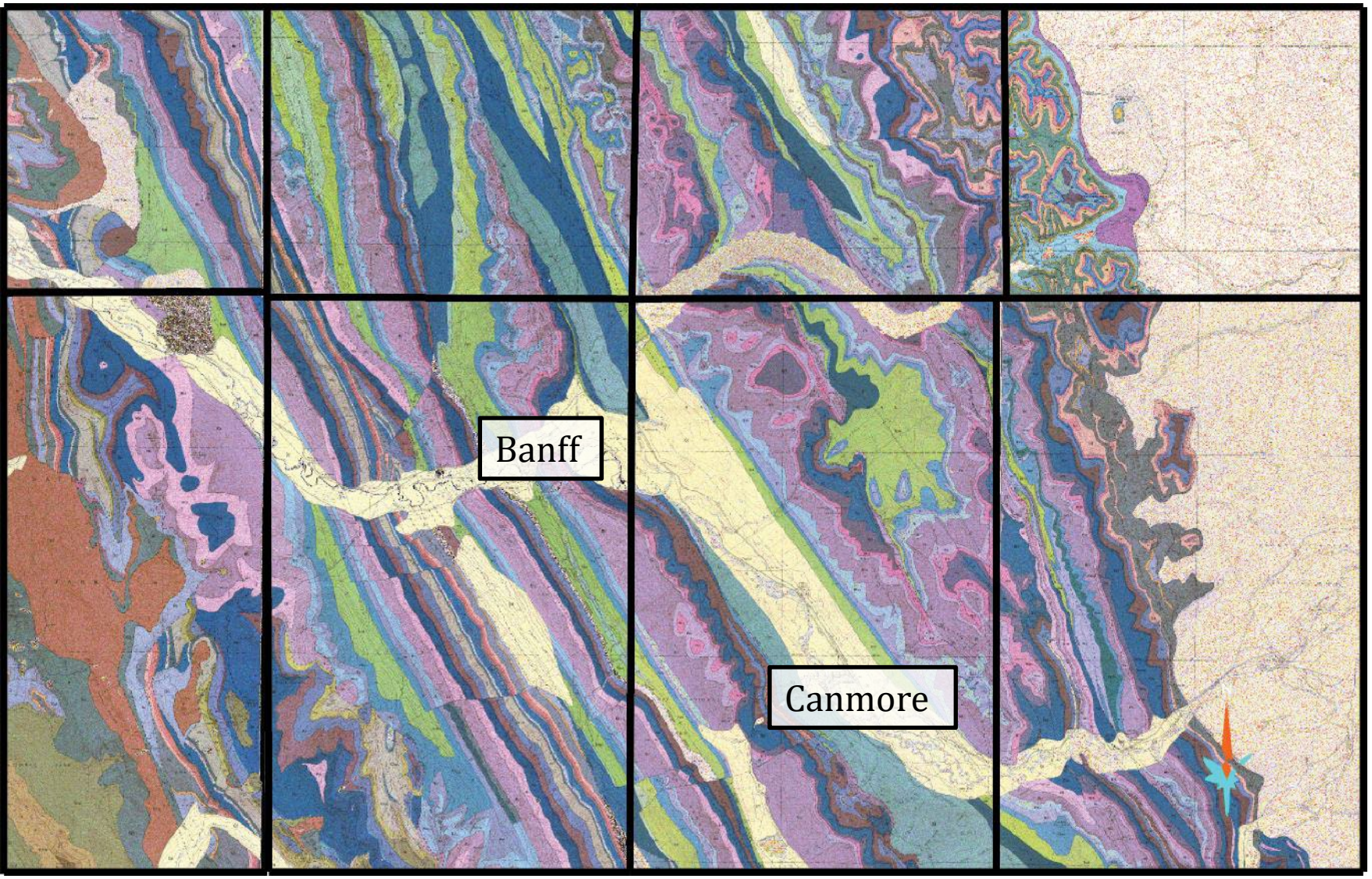


From Monger and Price, 2002



Map complied by Pana and Elgr, 2013

Geologic Maps of the Front Ranges



Produced by the Canadian Geologic Survey (1970-1980)

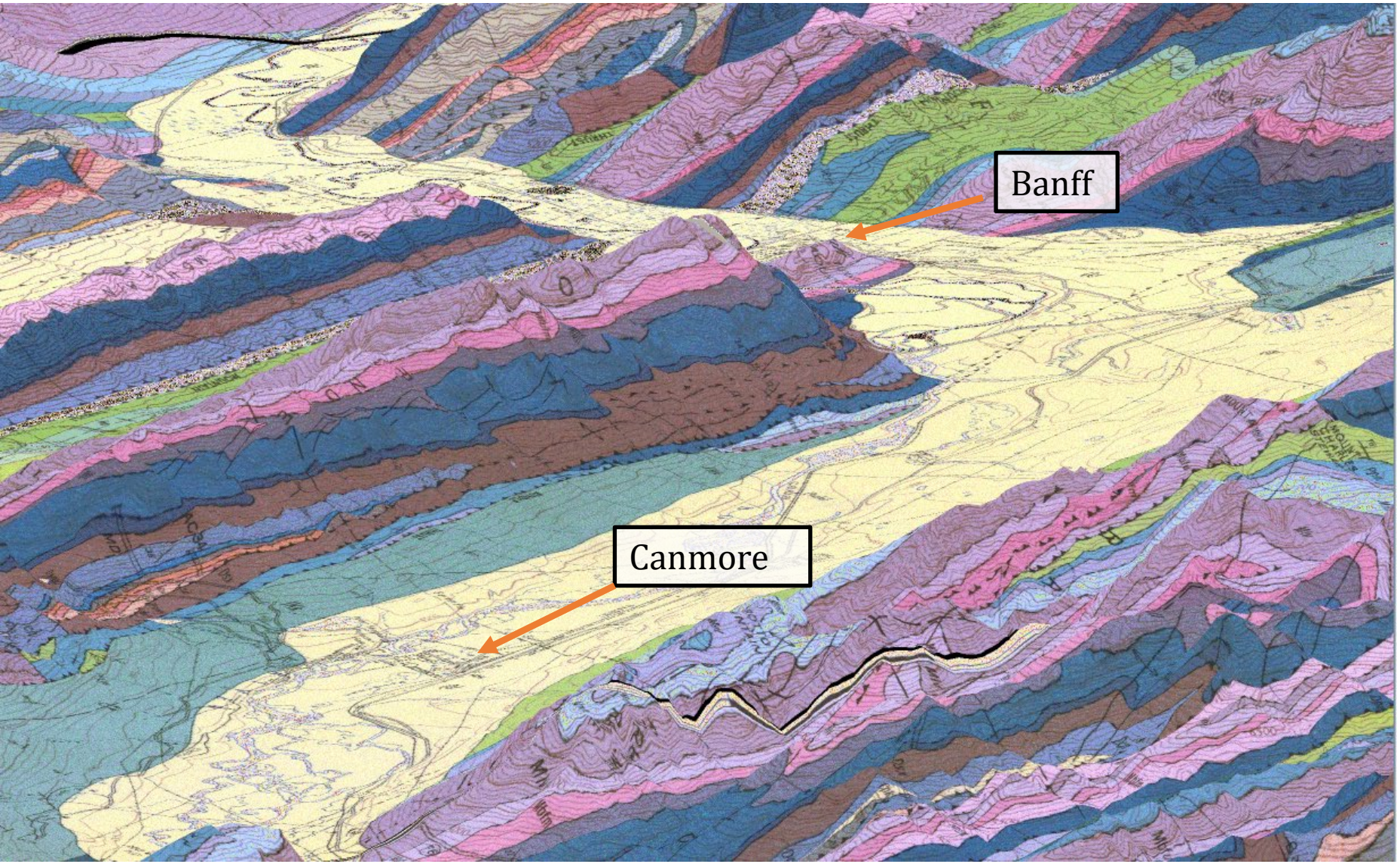
1:50,000 scale geologic maps

1:50,000 ≈ 25 m/pixel

Details the location of bedrock geology and faults along with Quaternary Deposits

Angle of perspective view

Perspective View of an Exhumed Mountain Belt



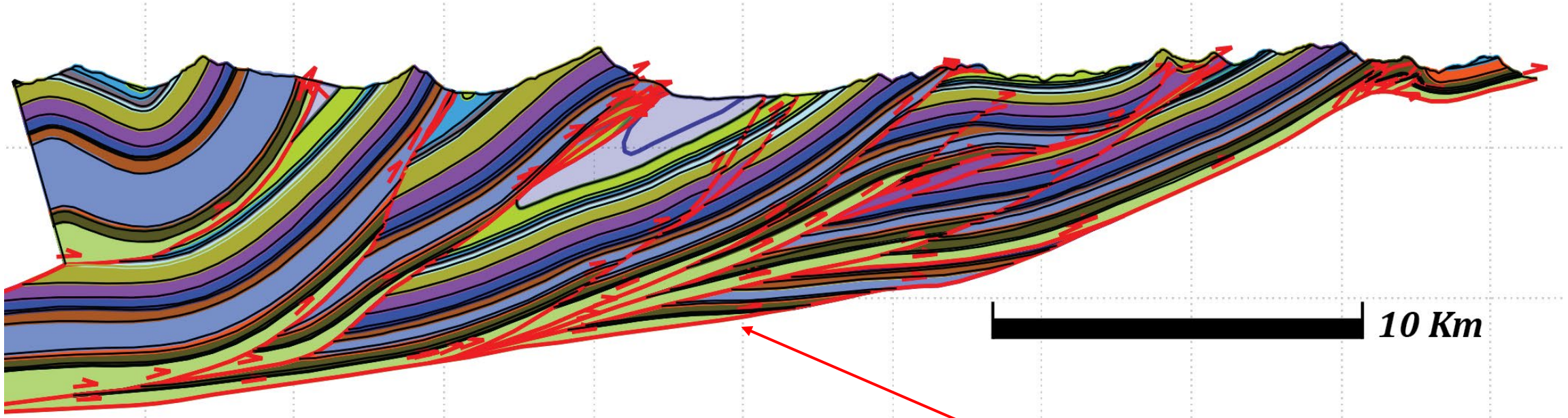
Geologic Maps 1:50000 scale

DEM from University of Calgary 10m/pixel (Satellite based)

We record the geometry of a fold and thrust belt at a mid-crustal level

The DEM's resolution is sufficient to represent the local fold and thrust belt geometry

Previous Interpretations of the Front Ranges



Interpretation from Price and Fermour, 1985;
adapted by Welch

Basement-Sediment Transition from Bailey et al., 1966

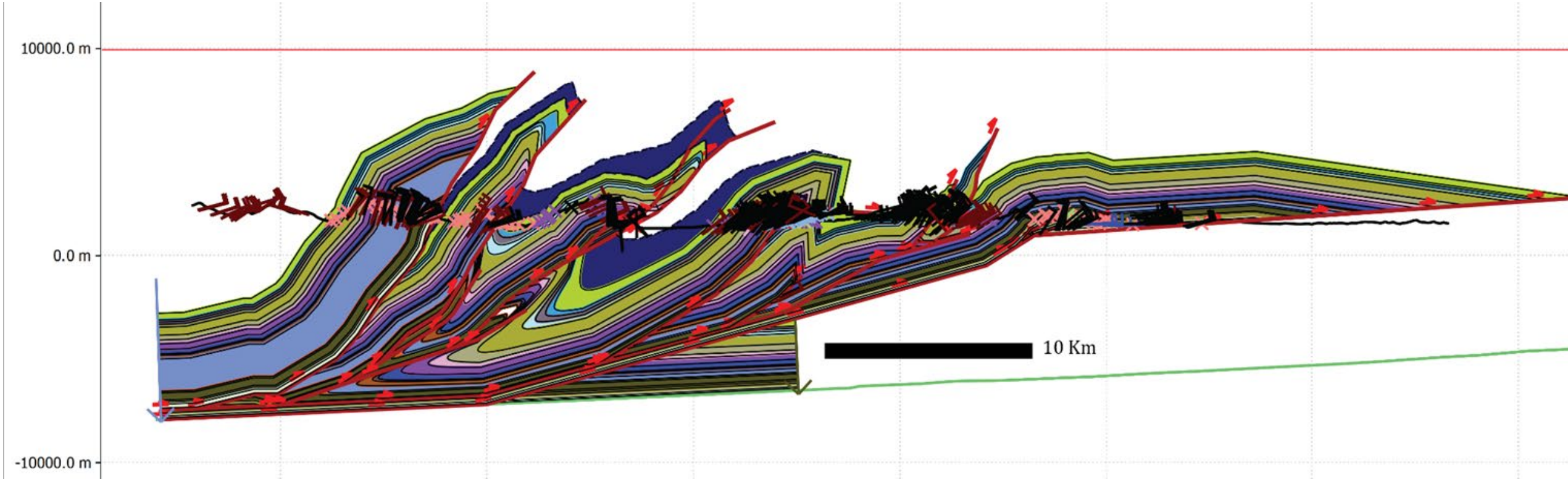
General Features of Price and Fermour's 1985 Cross Section:

Thin-Skinned Fold and Thrust Belt with one Regional detachment (Front Ranges)

Imbricated Thrust Sheets with a listric geometry

Break Forward sequence

New Retro-deformable Cross Section of the Front Ranges



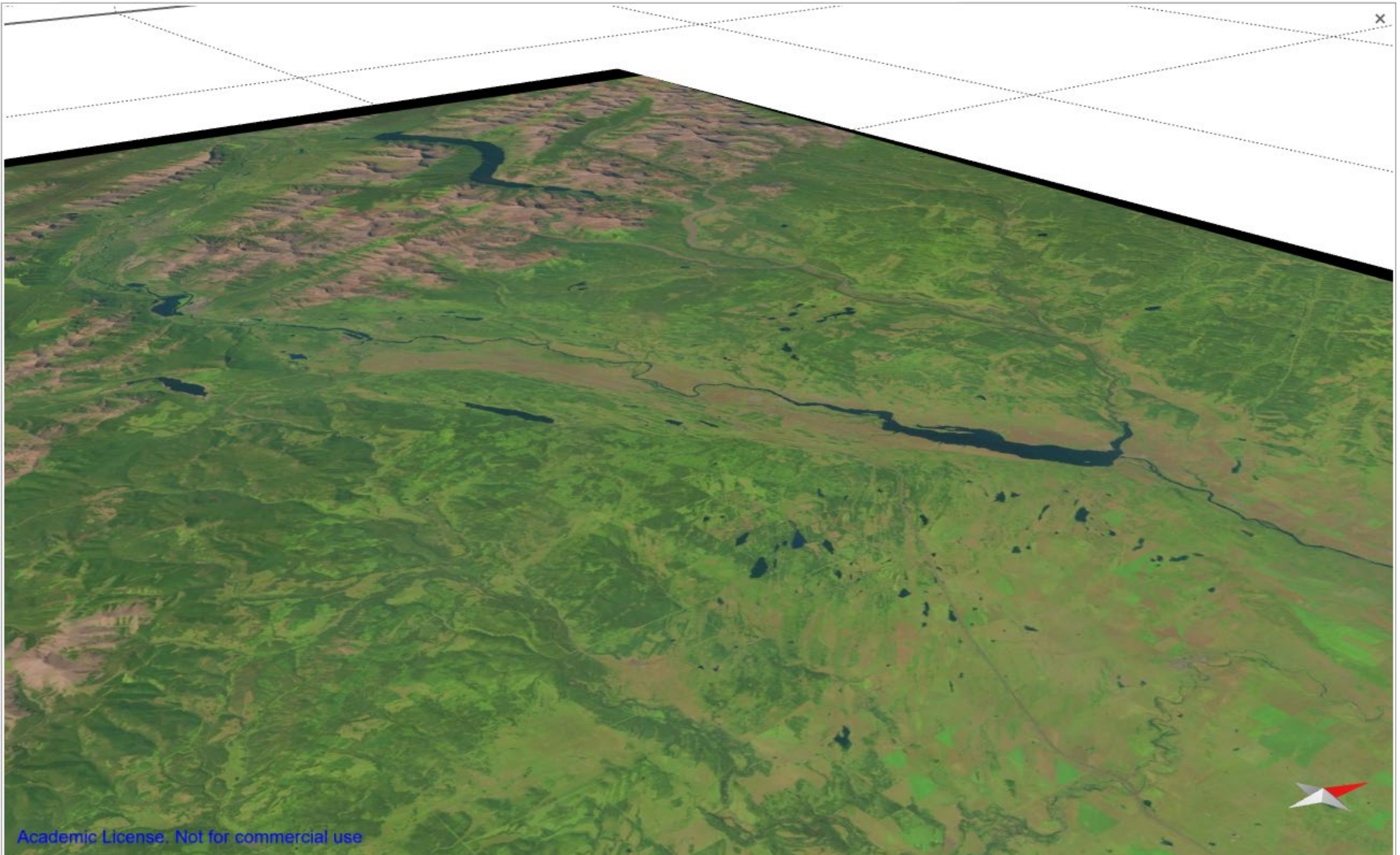
Our Conclusions:

Thin-Skinned Fold and Thrust Belt with multiple detachments

Imbricate system made up of fault-bend, fault-propagation, and break-through fault-propagation folds

Heterogeneity in the timing of thrusting; both break-forward and break-backward (out of sequence) thrusting

High-Resolution Remote-Sensing Datasets



Landsat Imagery:
(10m/Pixel)

Google Earth Imagery:

(1-2m/Pixel)

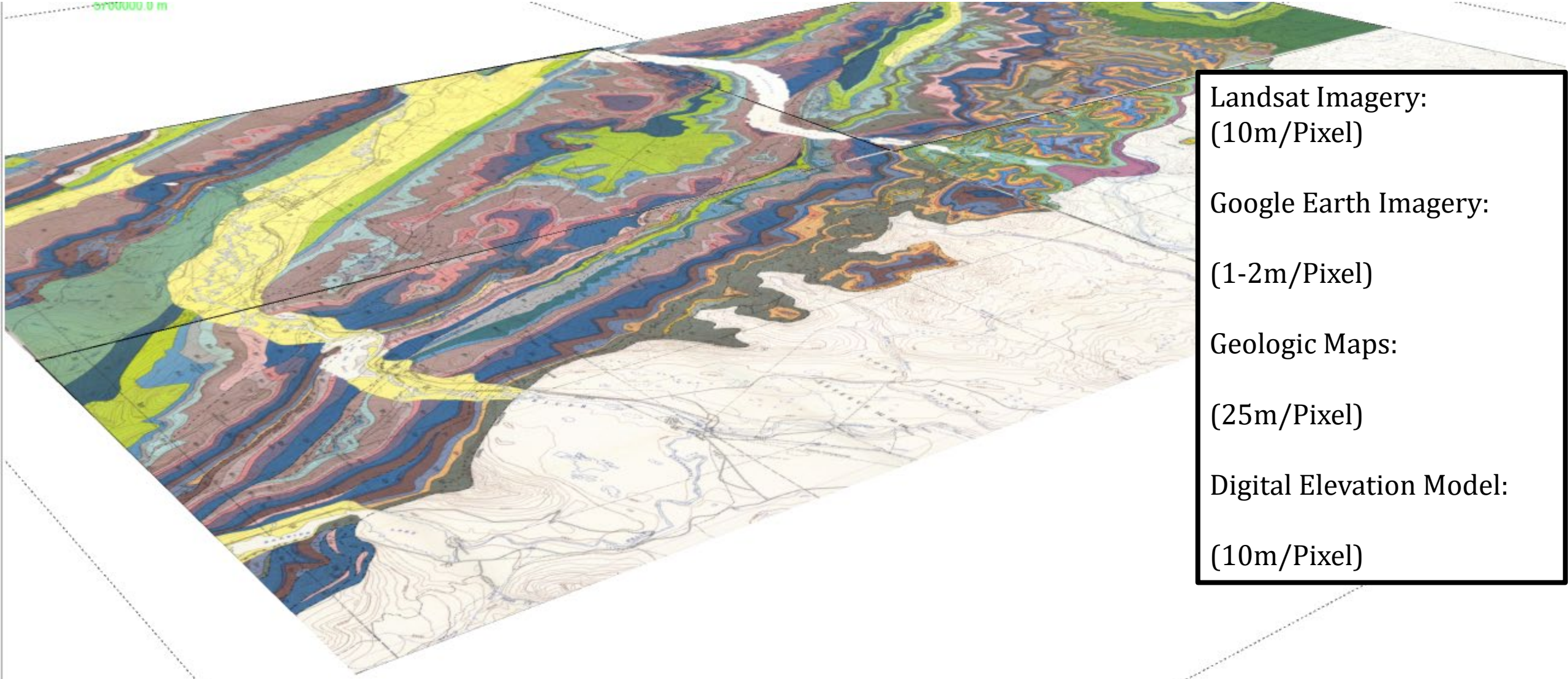
Geologic Maps:

(25m/Pixel)

Digital Elevation Model:

(10m/Pixel)

High-Resolution Remote-Sensing Datasets



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Geologic Maps:

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Digital Elevation Model:

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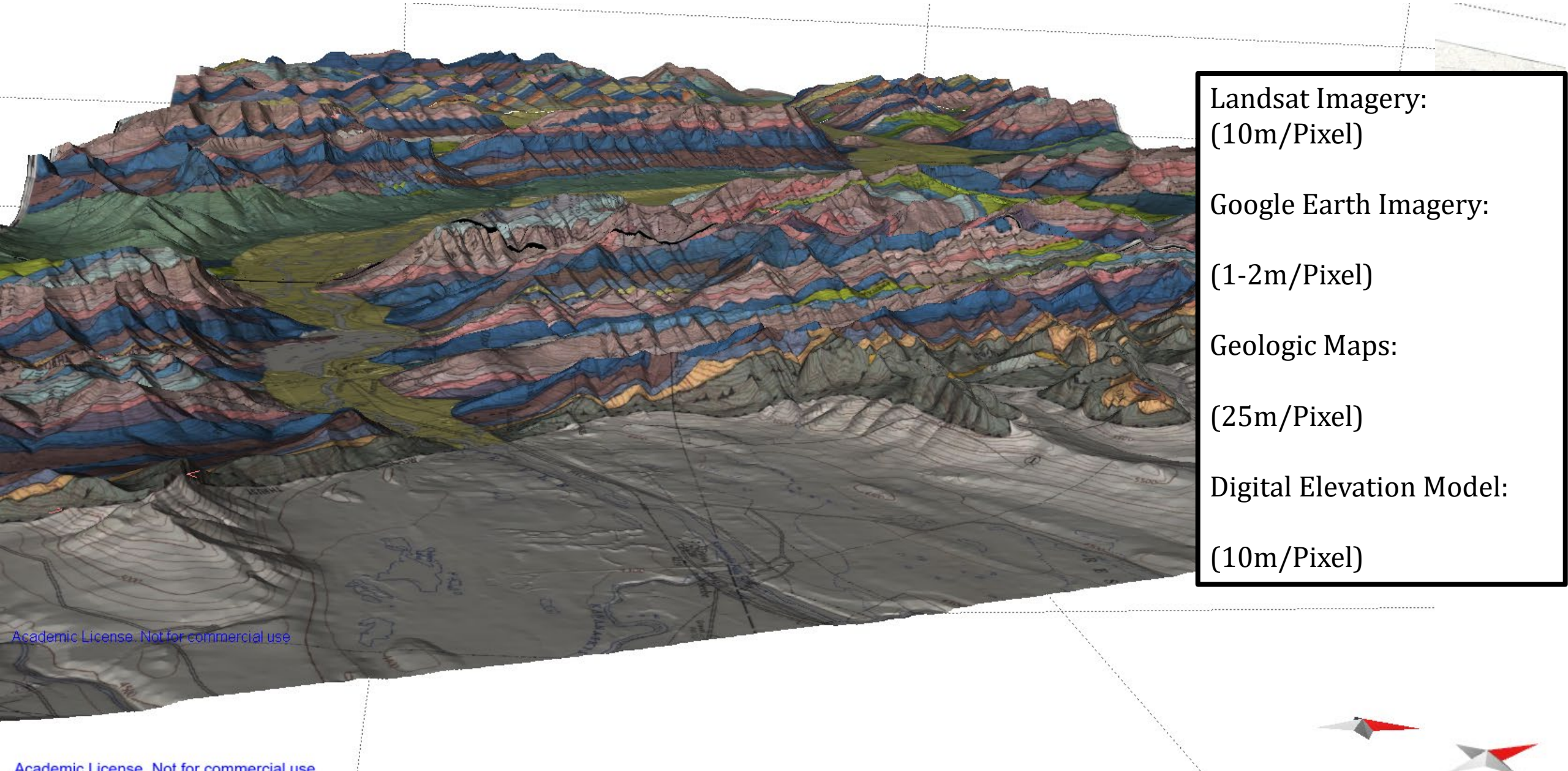

Landsat Imagery:
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Google Earth Imagery:

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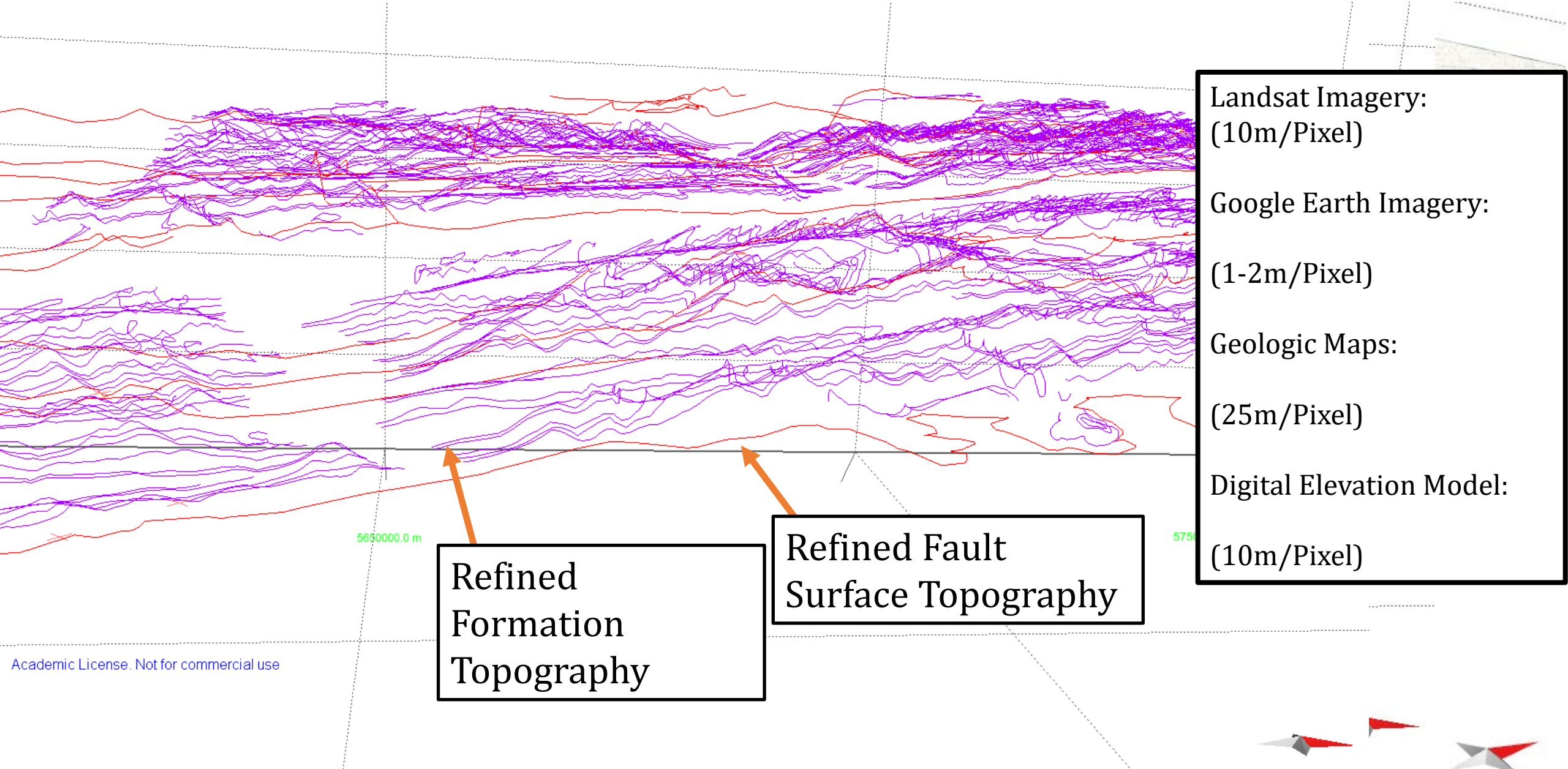


Landsat Imagery:
(10m/Pixel)

Google Earth Imagery:

(1-2m/Pixel)

Geologic Maps:

(25m/Pixel)

Digital Elevation Model:

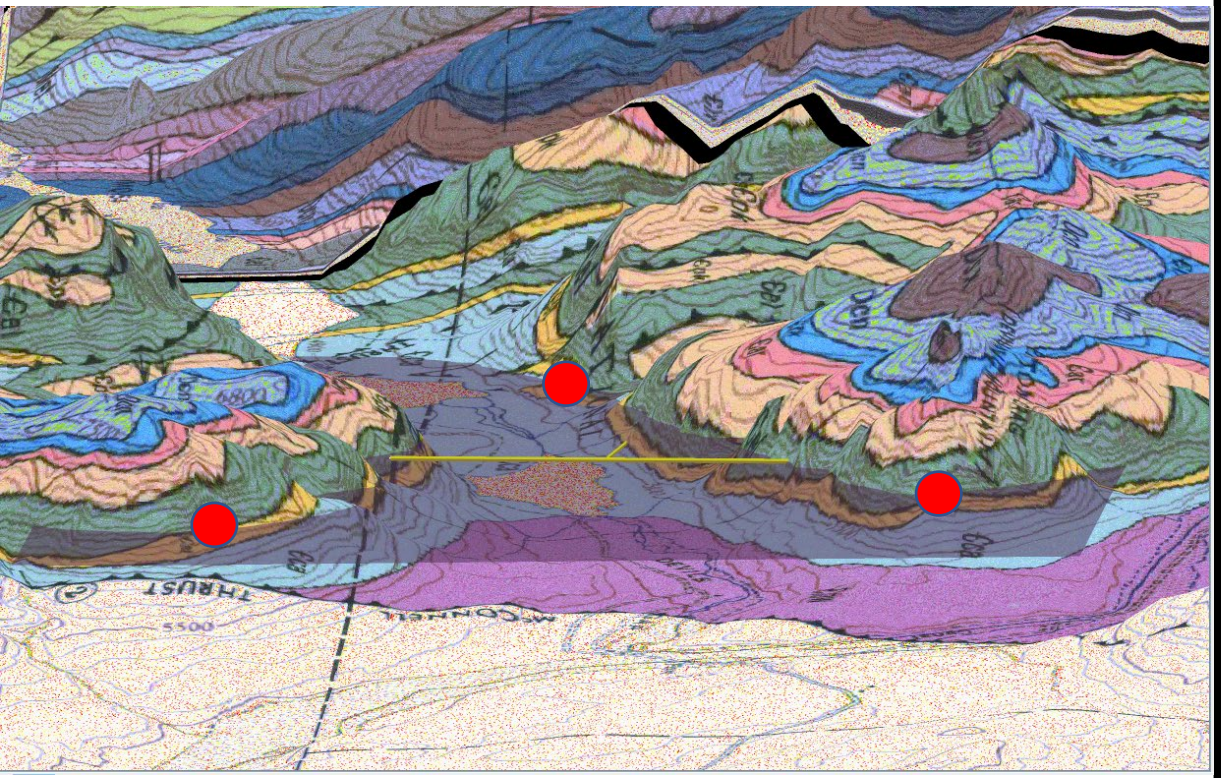
(10m/Pixel)

Refined Formation Topography

Refined Fault Surface Topography

Plane Fitting Methods for Attitude Measurements

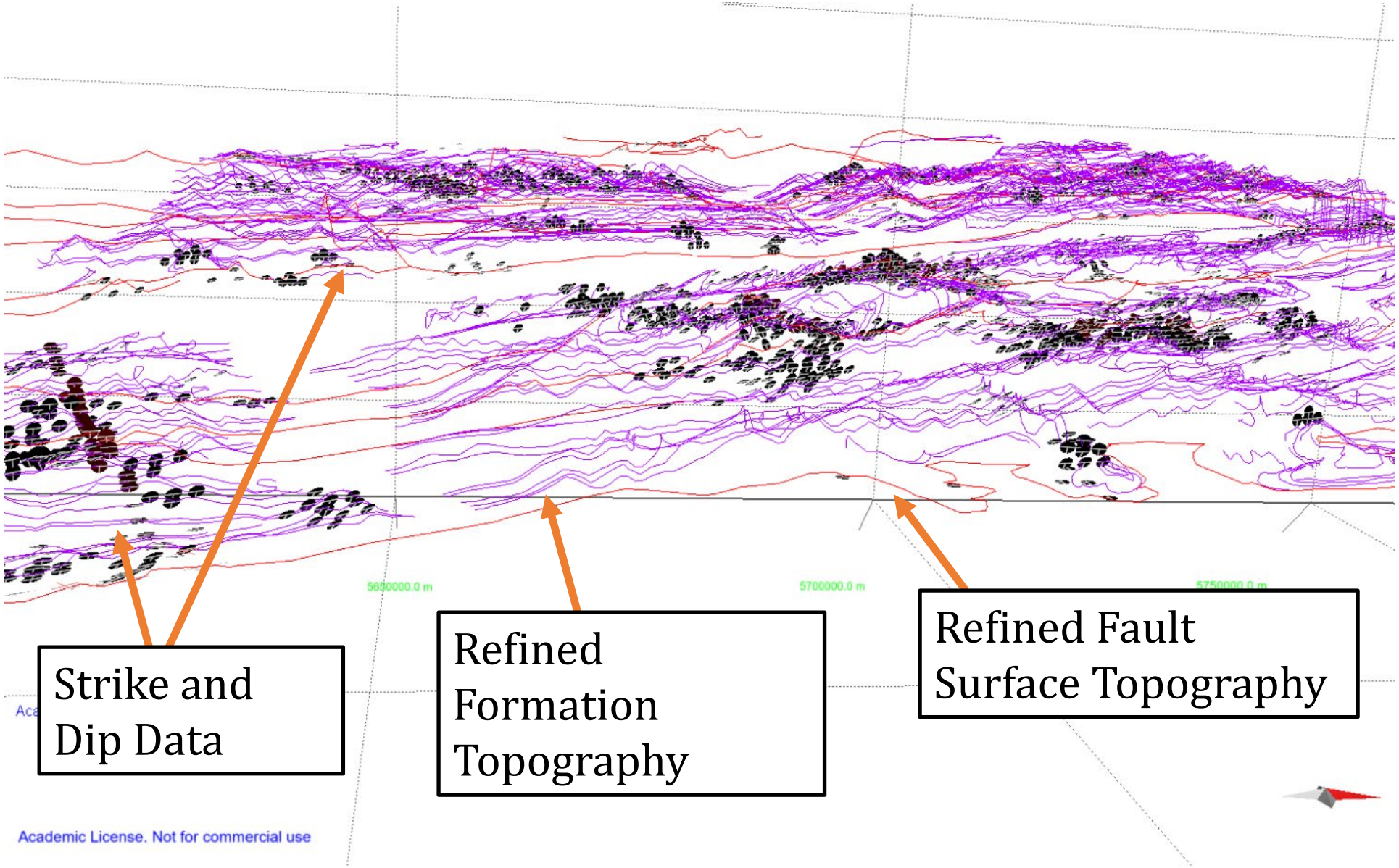
Remote Observations



Picked points from refined horizons

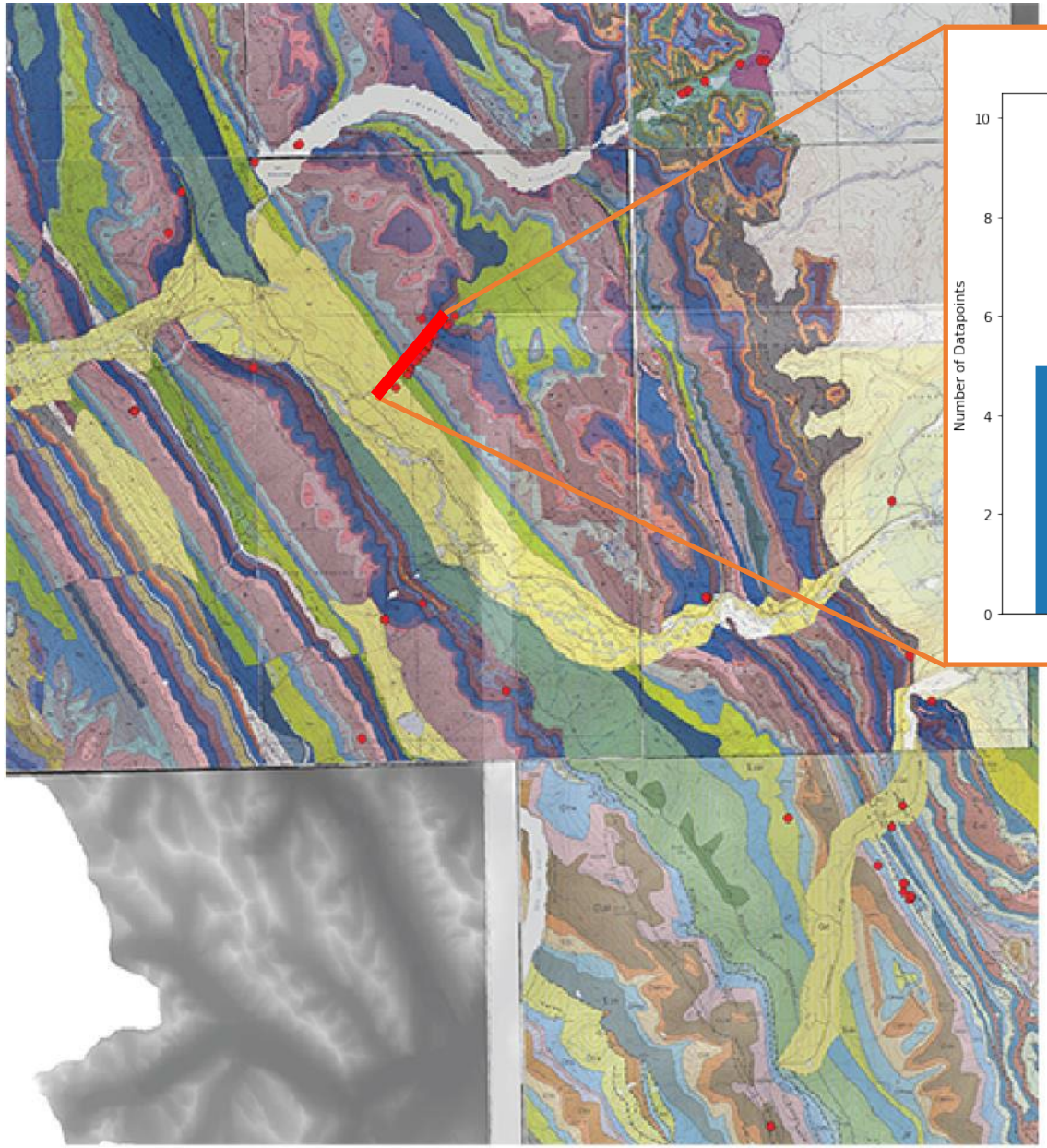
Field Observations

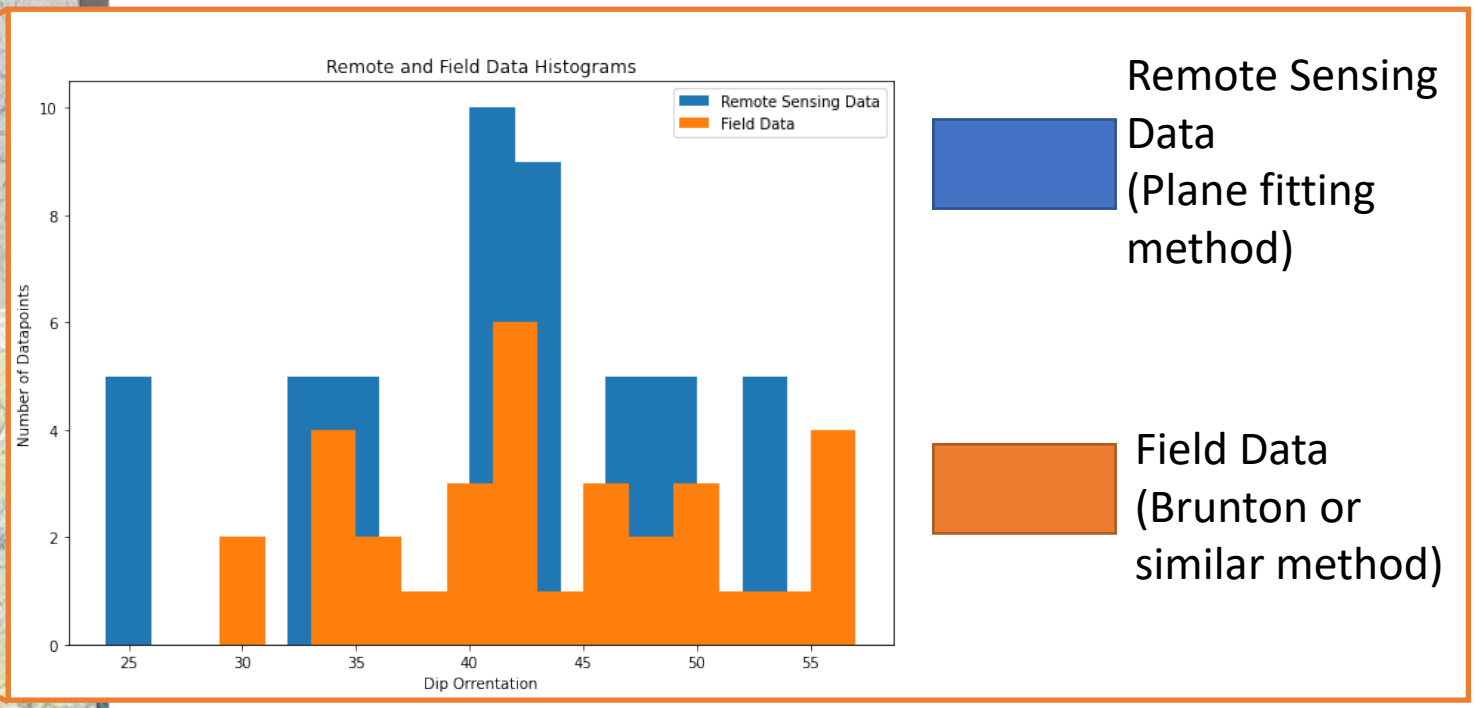
Extracting Strike and Dip Measurements from Remote Datasets



Using remote sensing techniques, we extracted over 2,000 attitude measurements for bedding and fault horizons.

Comparison to Classical Methods



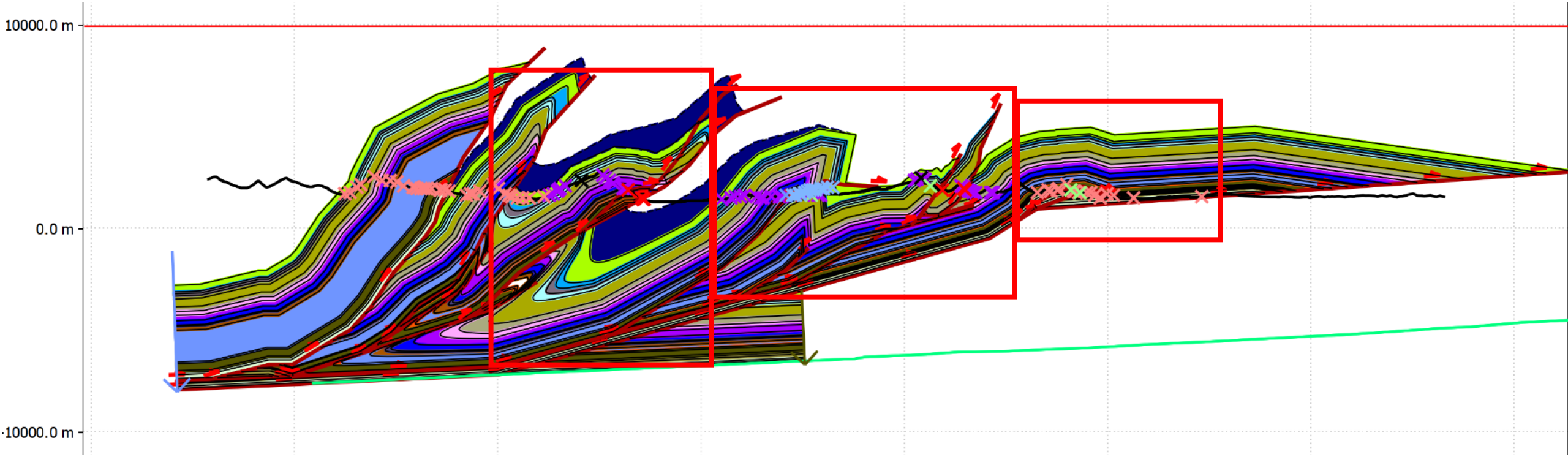


Takeaways:

-Plane Fitting and Field Observations record regional attitude measurements

-Plane Fitting does not record small scale structures

Case Study Regions



Our Results:

Thin-Skinned Fold and Thrust Belt with Multiple Detachments

Imbricate system made up of fault-bend and fault-propagation folds; break-forward thrusting sequence

Breakthrough fault-propagation folds exhibit out-of-sequence thrusting

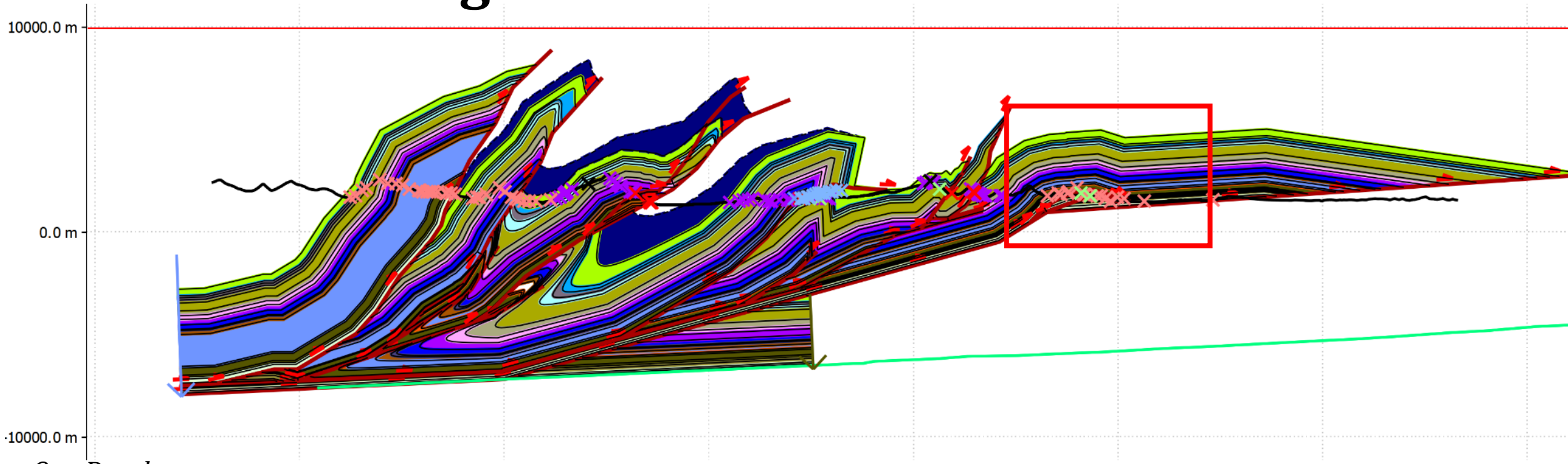
Case Study Regions:

Area 1: The Costigan Thrust Zone

Area 2: The Rundle Thrust Zone

Area 3: The Inglismalide Thrust

Area 1: The Costigan Thrust



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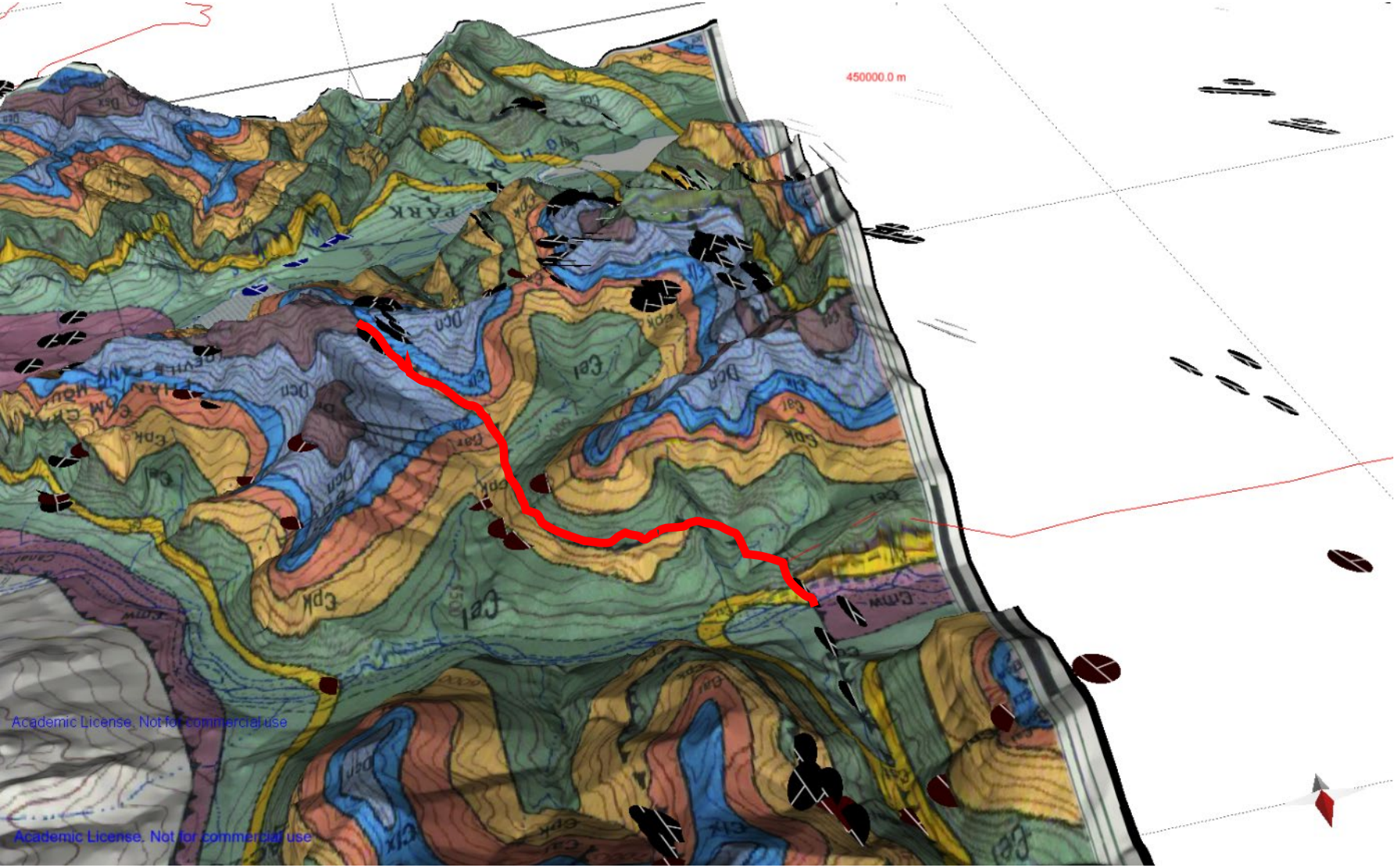
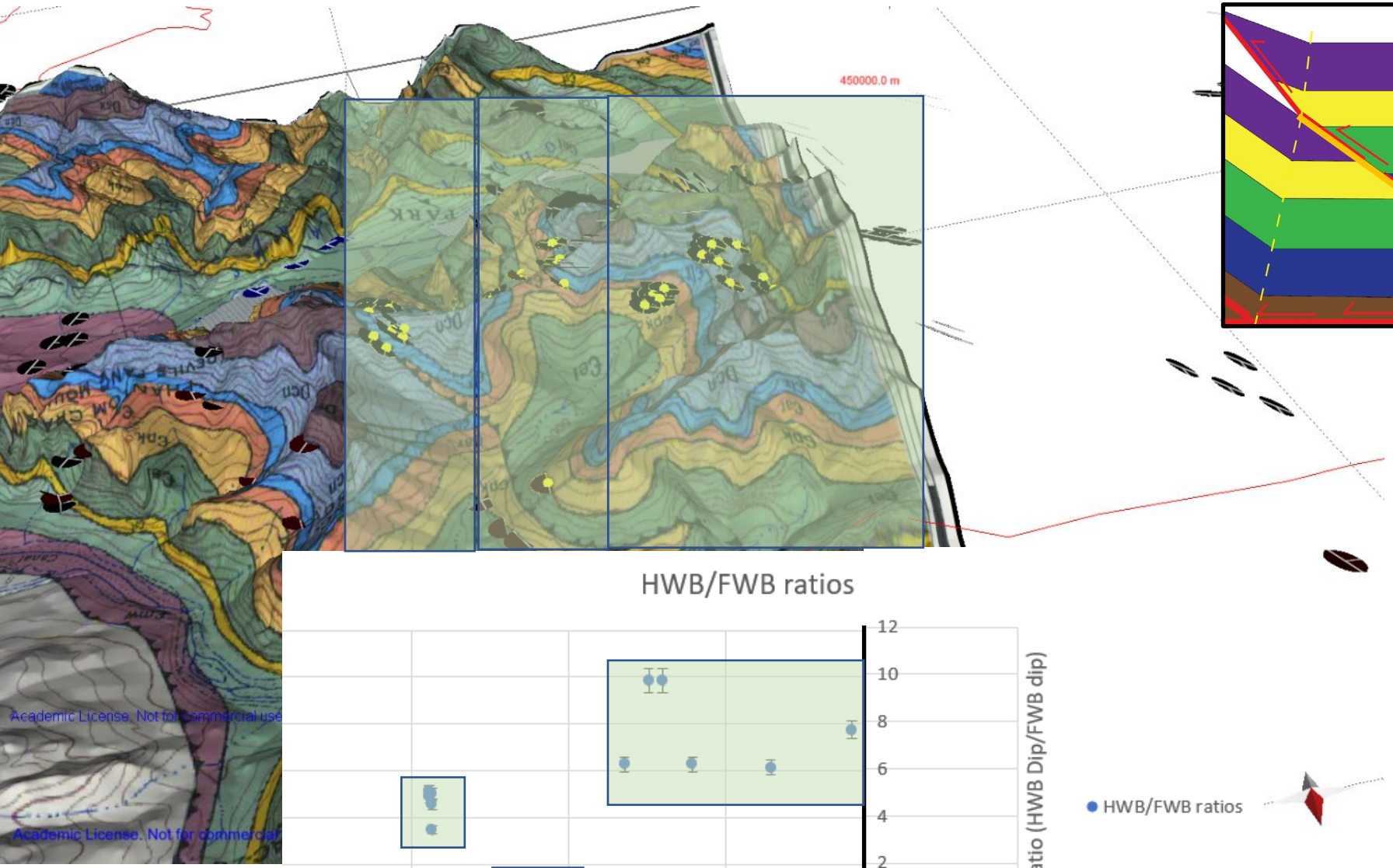
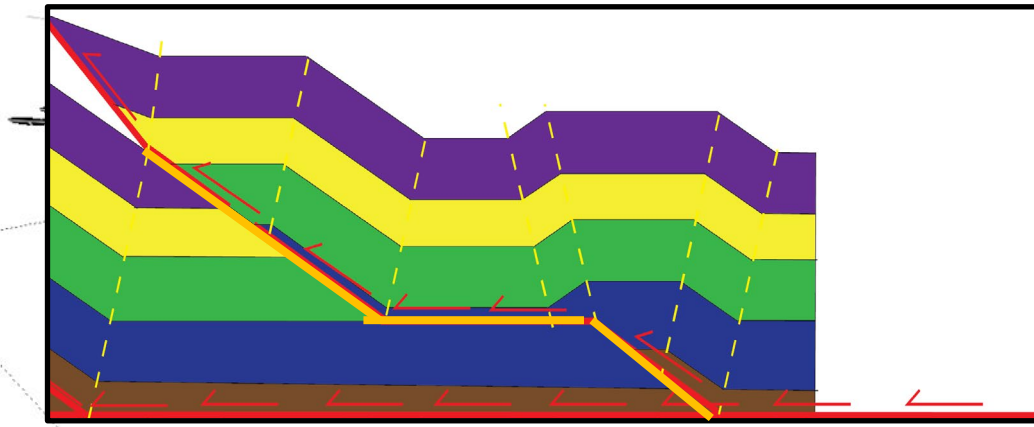
Data from the Costigan Thrust



FWB dips have an average dip of 3.4 +/- 0.3 degrees

Data from the Costigan Thrust



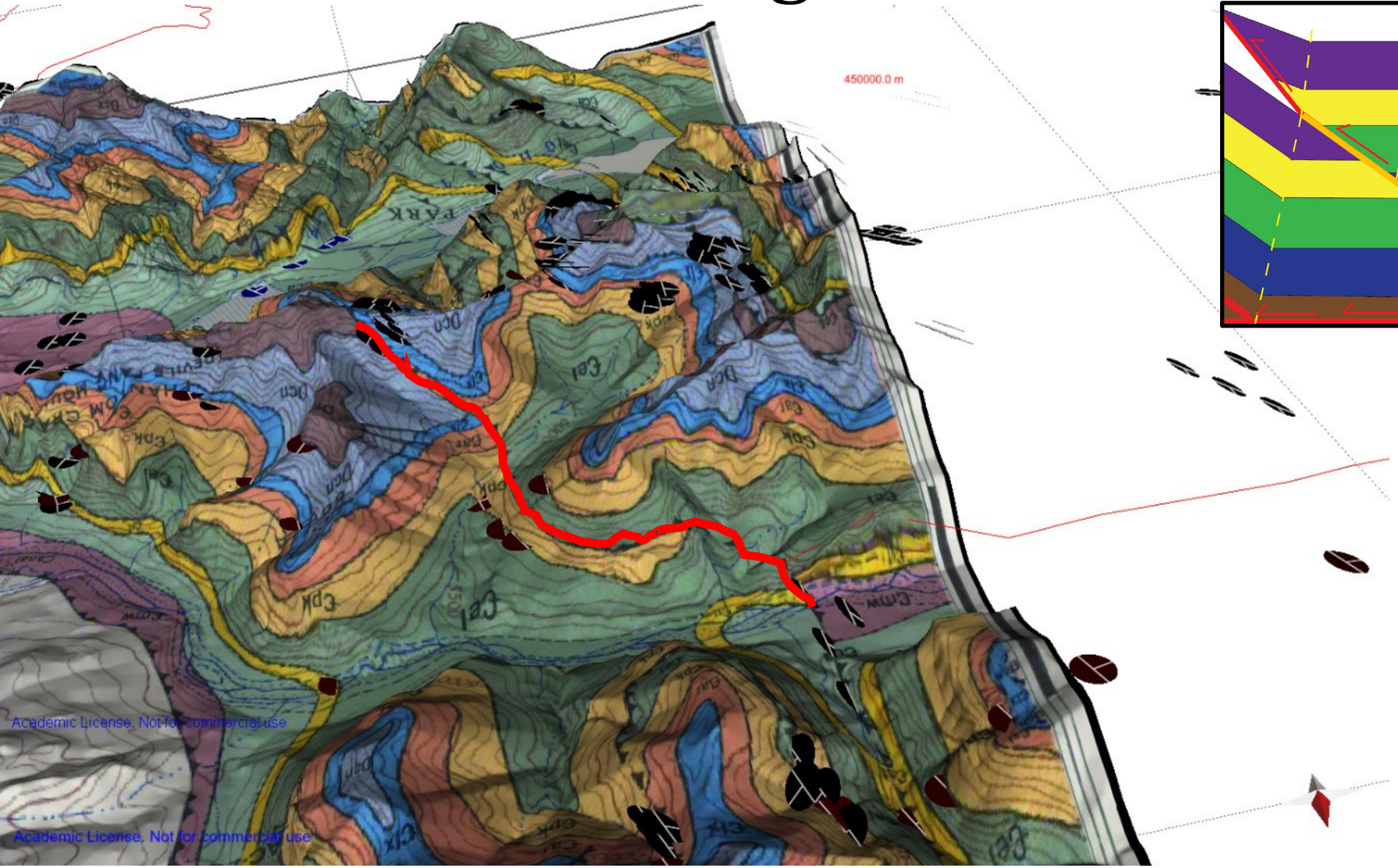


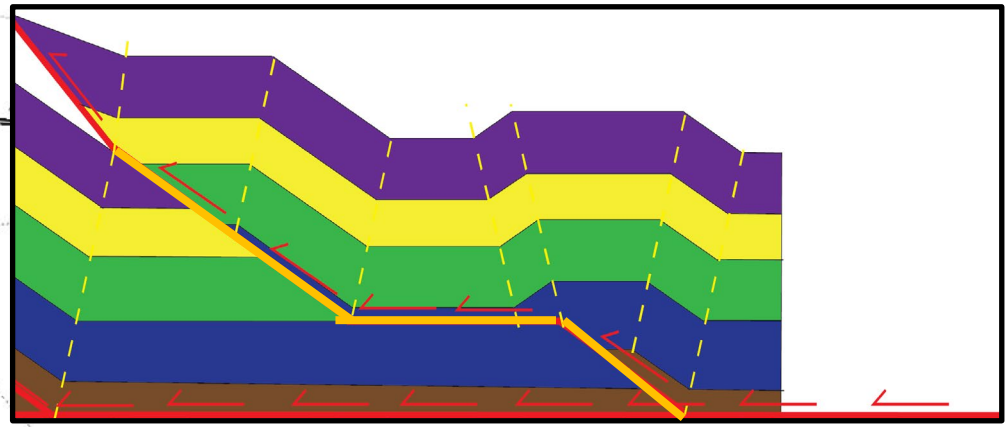
FWB dips have an average dip of 3.4 +/- 0.3 degrees

A HWB/FWB dip ratio of 1 indicates a detachment

A Greater than one HWB/FWB dip ratio indicates a ramp.

Data from the Costigan Thrust

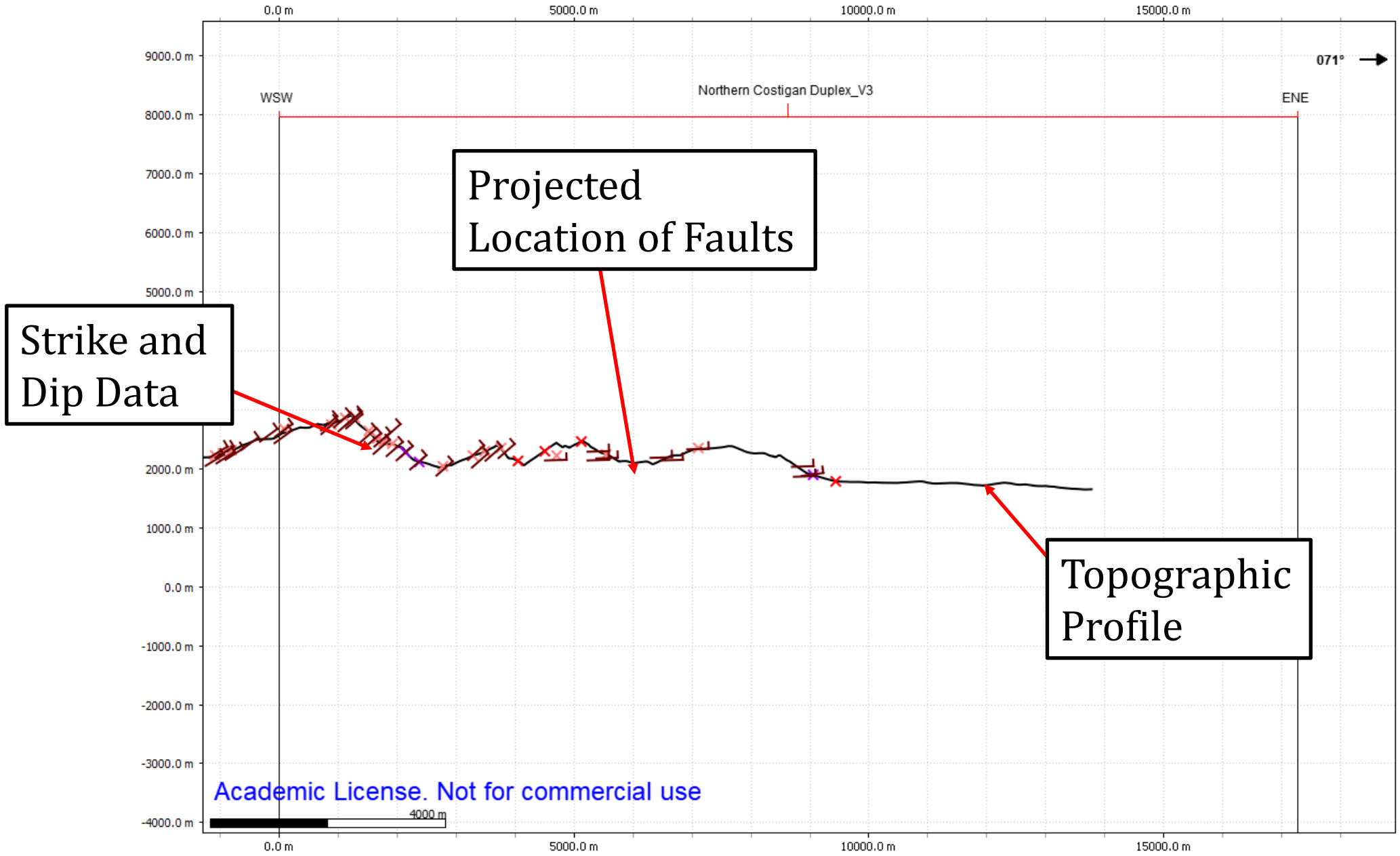




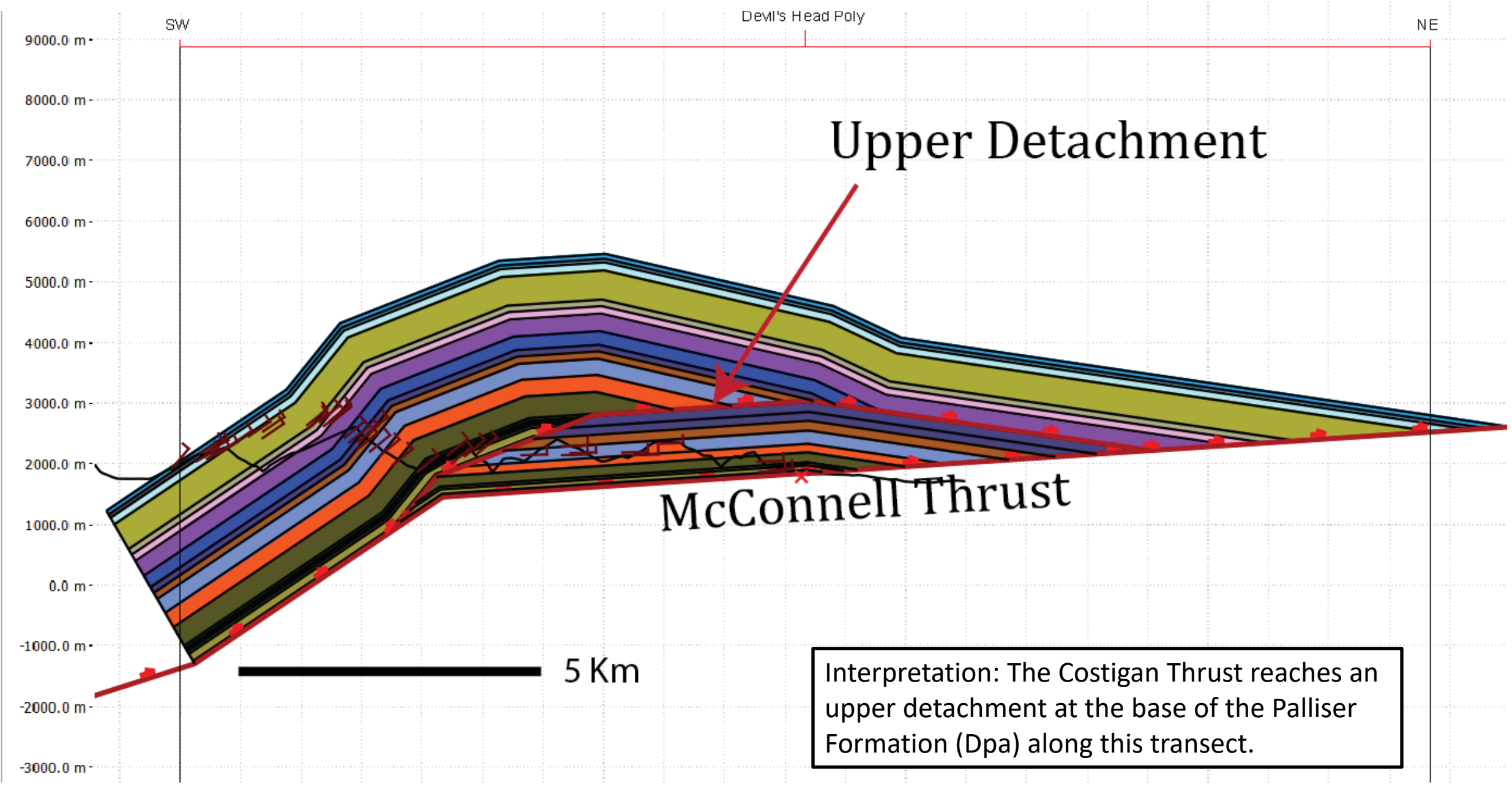
Costigan Thrust has a ramp-flat-ramp pattern

This indicates that the Costigan reaches and upper detachment

Structural Analysis of the Costigan Fault

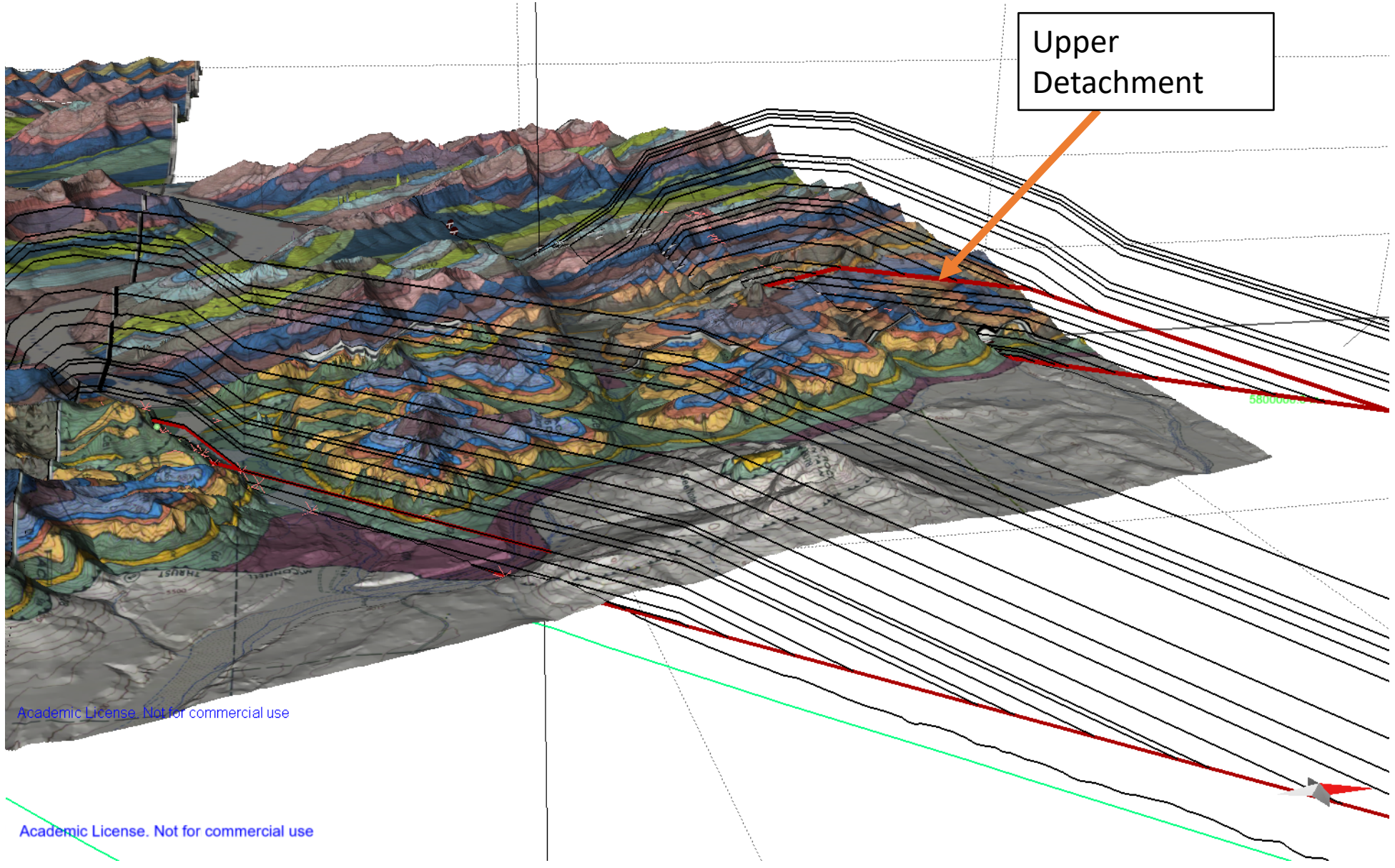


Interpretation of Multiple Detachments



Interpretation: The Costigan Thrust reaches an upper detachment at the base of the Palliser Formation (Dpa) along this transect.

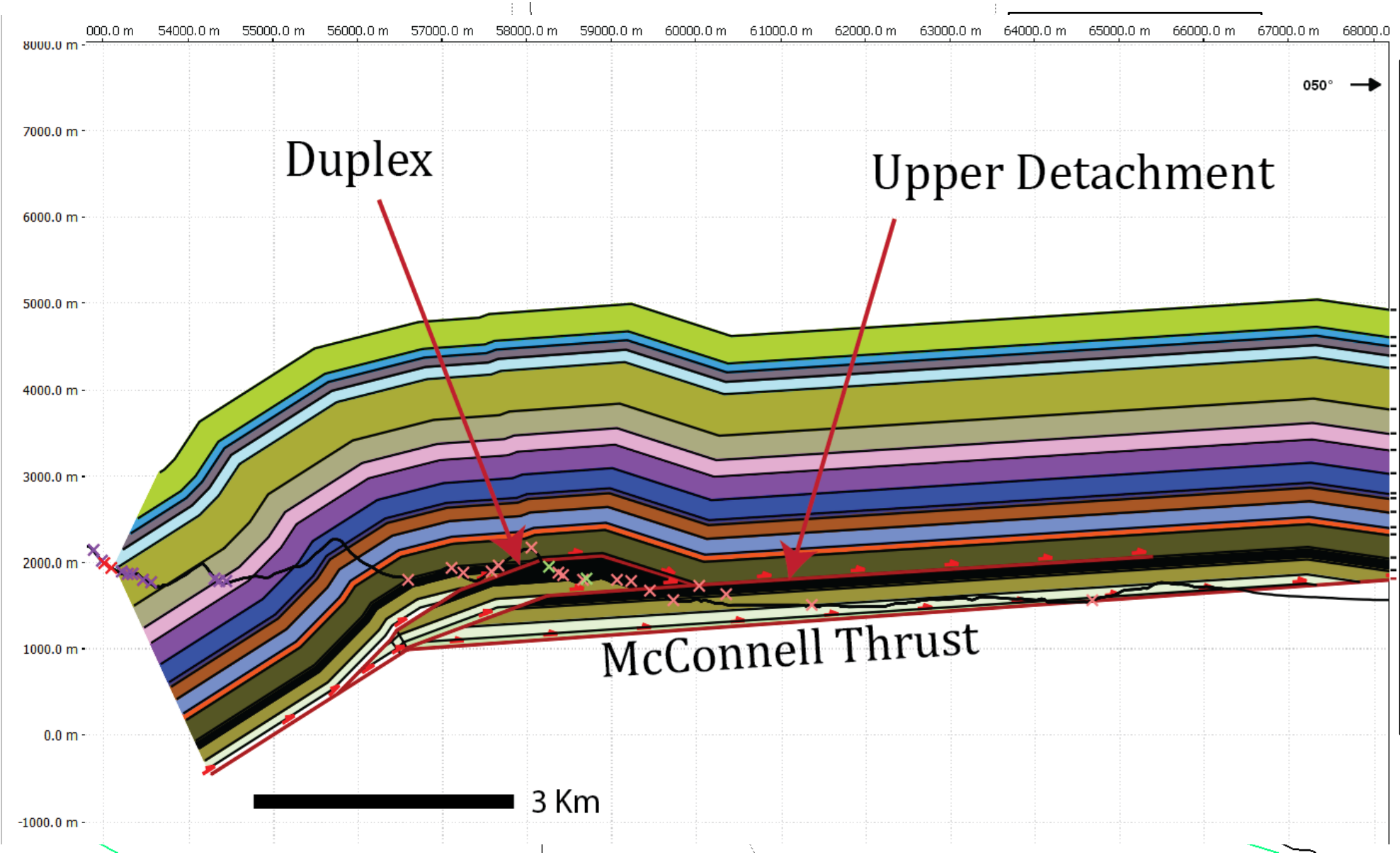
Multiple Detachments are Consistent Along Strike



The Costigan reaches a detachment in the Cambrian Stephen Formation

Instances of the Costigan involving an upper detachment are commonplace.

Multiple Detachments are Consistent Along Strike



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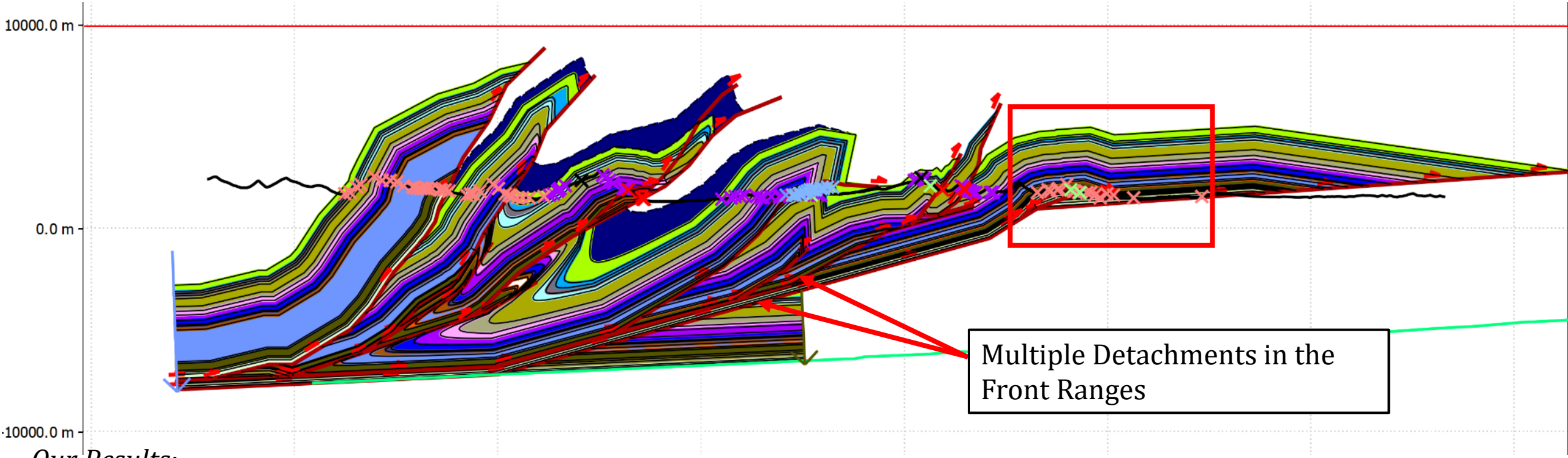
Area 1: The Costigan Thrust



Our Results:

Thin-Skinned Fold and Thrust Belt with Multiple Detachments

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Breakthrough fault-propagation folds exhibit out-of-sequence thrusting

Case Study Regions:

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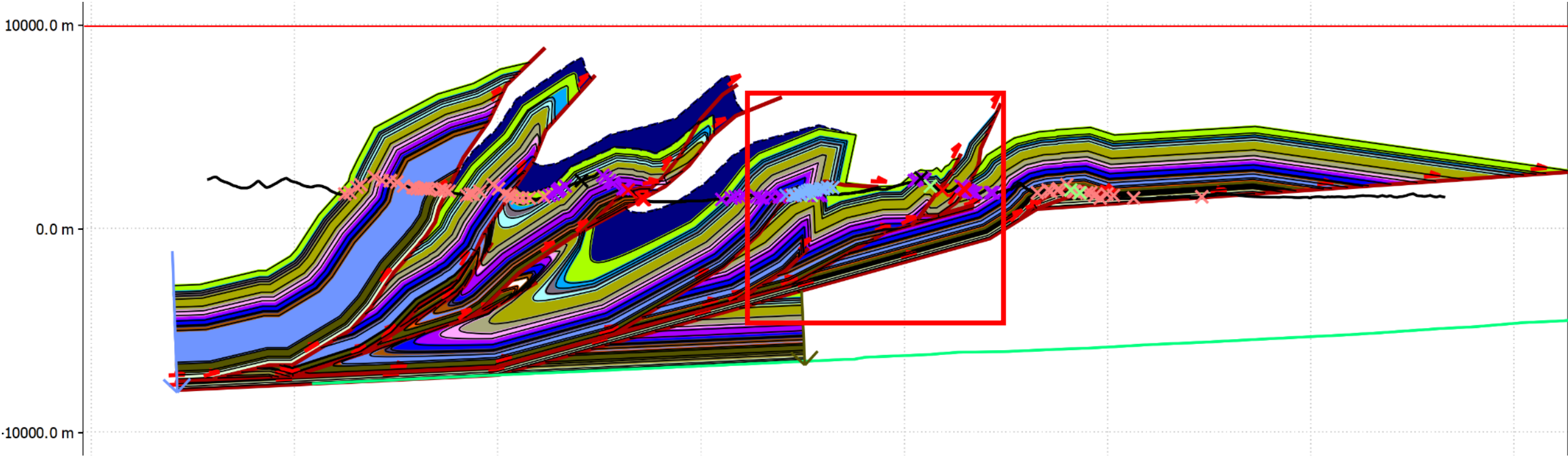
Area 2: The Rundle Thrust

Area 3: The Inglismalide Thrust

Area 2: The Inglismaldie Thrust



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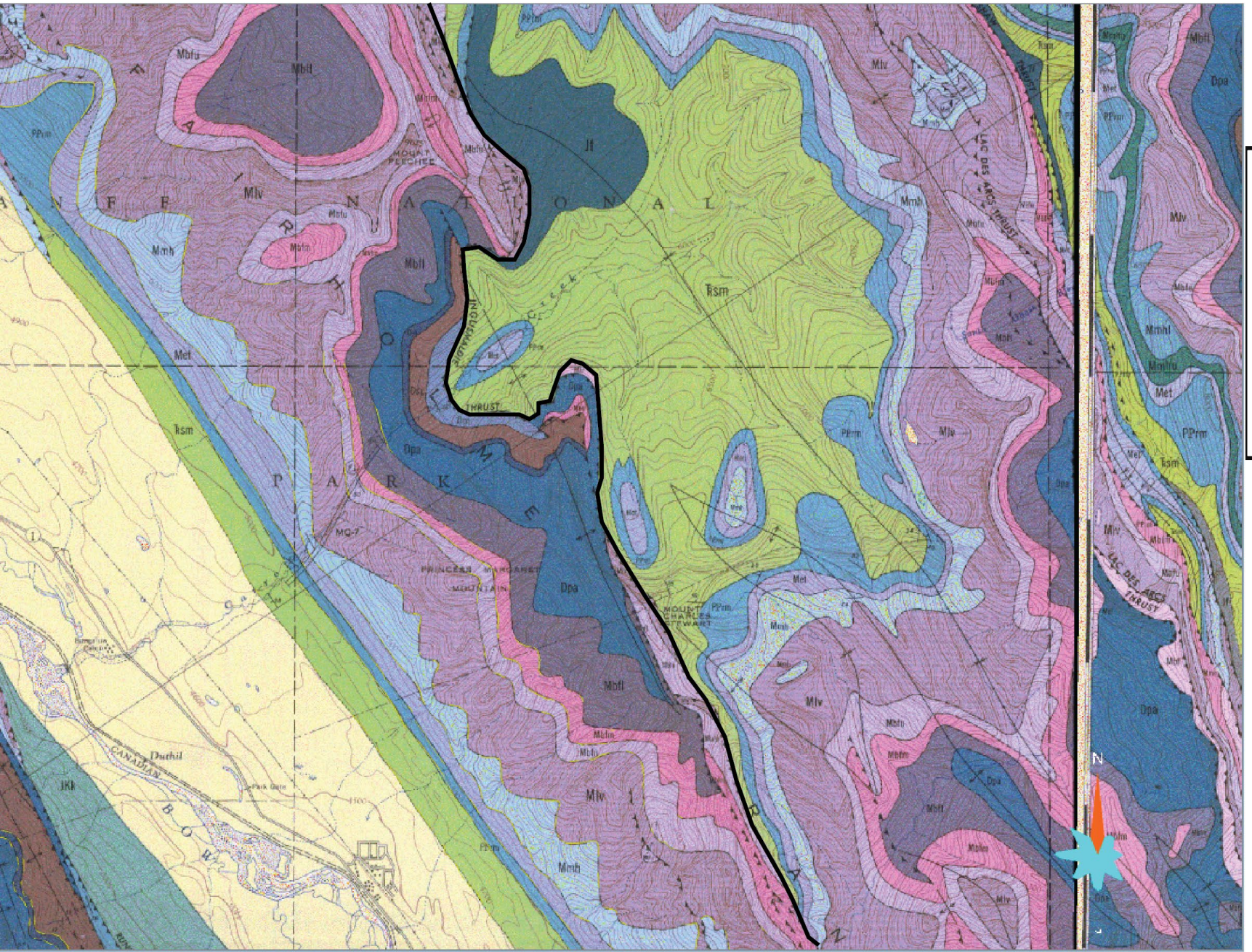
Area 1: The Costigan Thrust

Area 2: The Inglismalide Thrust

Area 3: The Rundle Thrust

Area 2: Map Pattern of the Inglismaldie Thrust

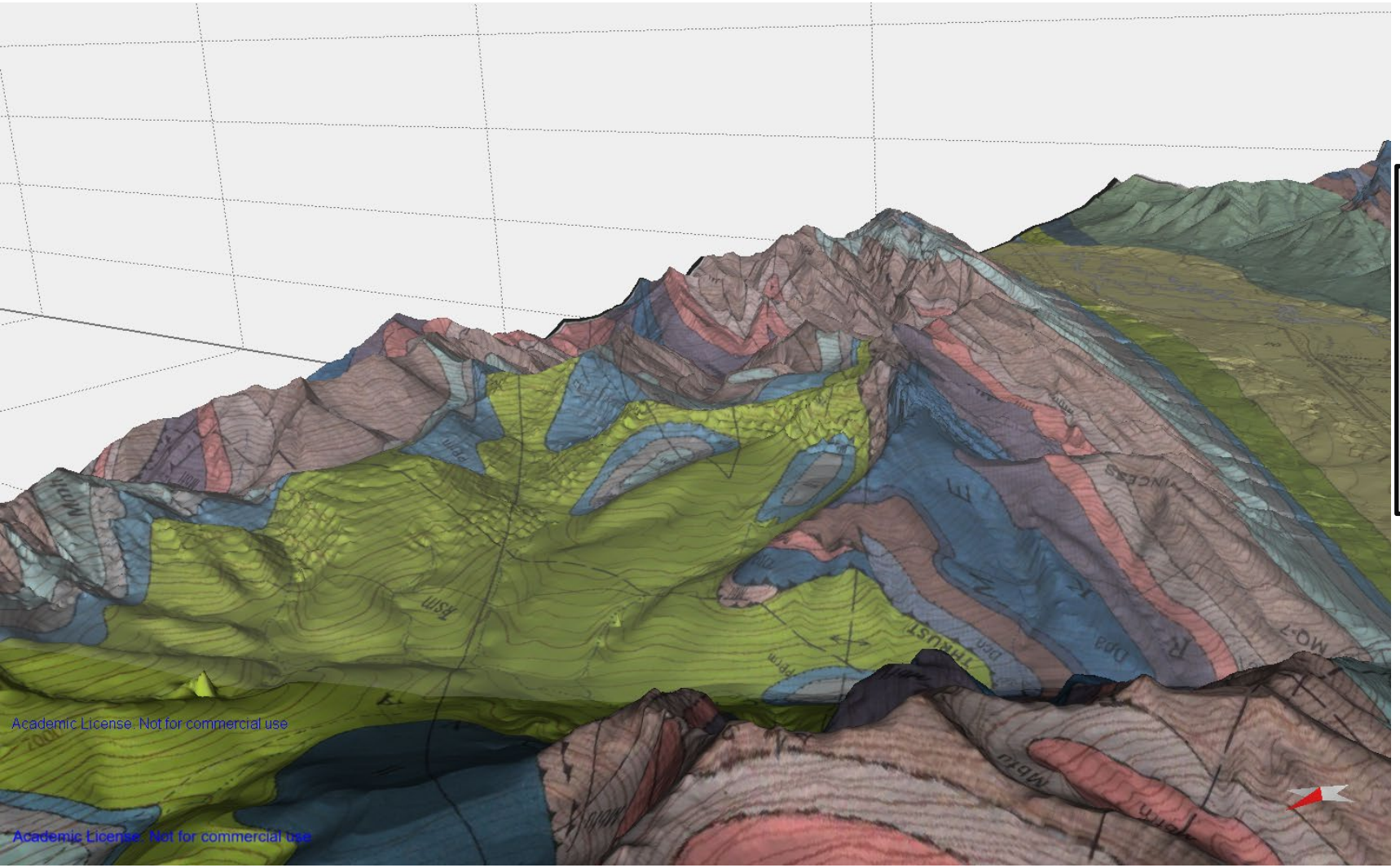


Observations:

The Inglsimadlie Thrust is locally folded.

Where the Inglsimaldie is folded there are horse tail splays

Area 2: Map Pattern of the Inglismaldie Thrust



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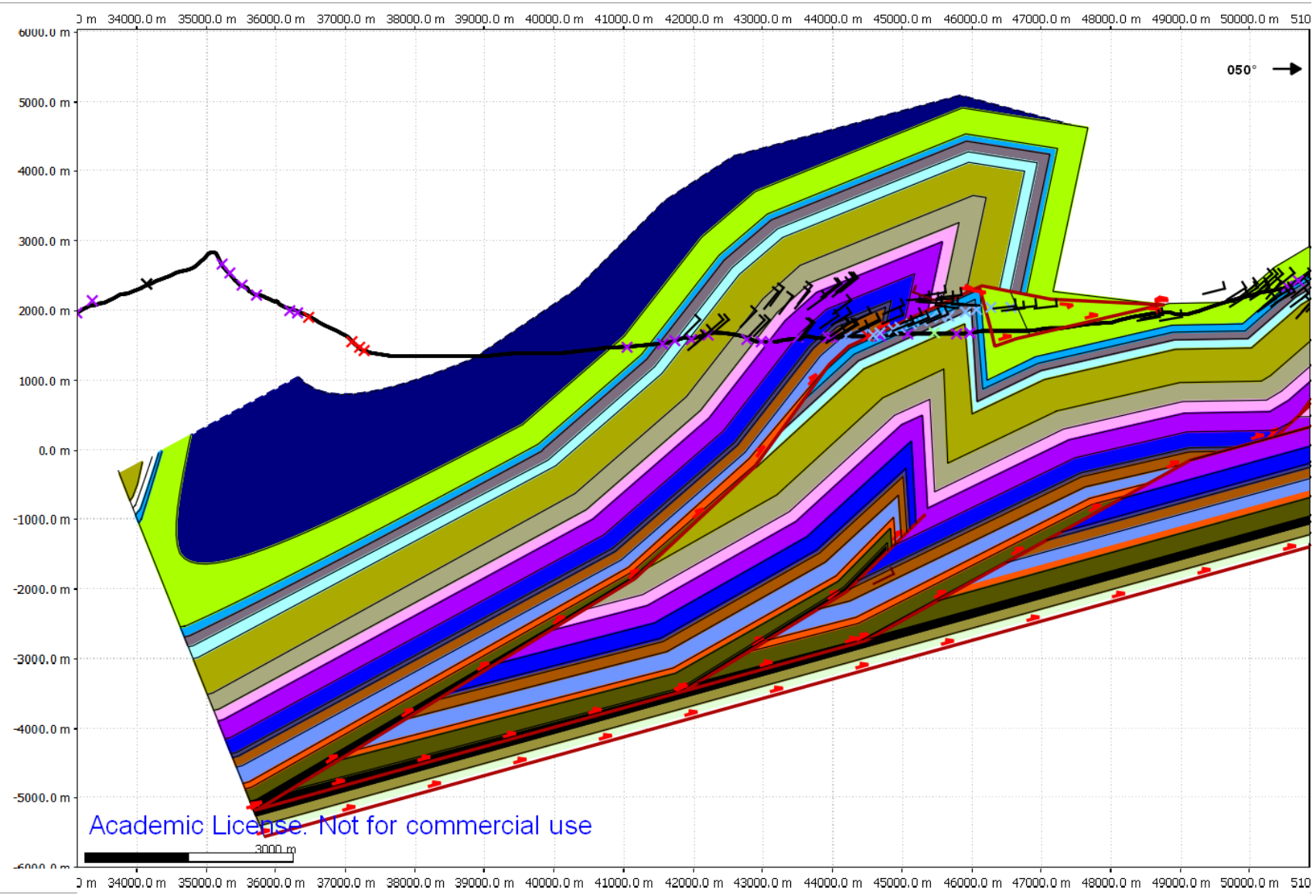
The Inglismaldie Thrust



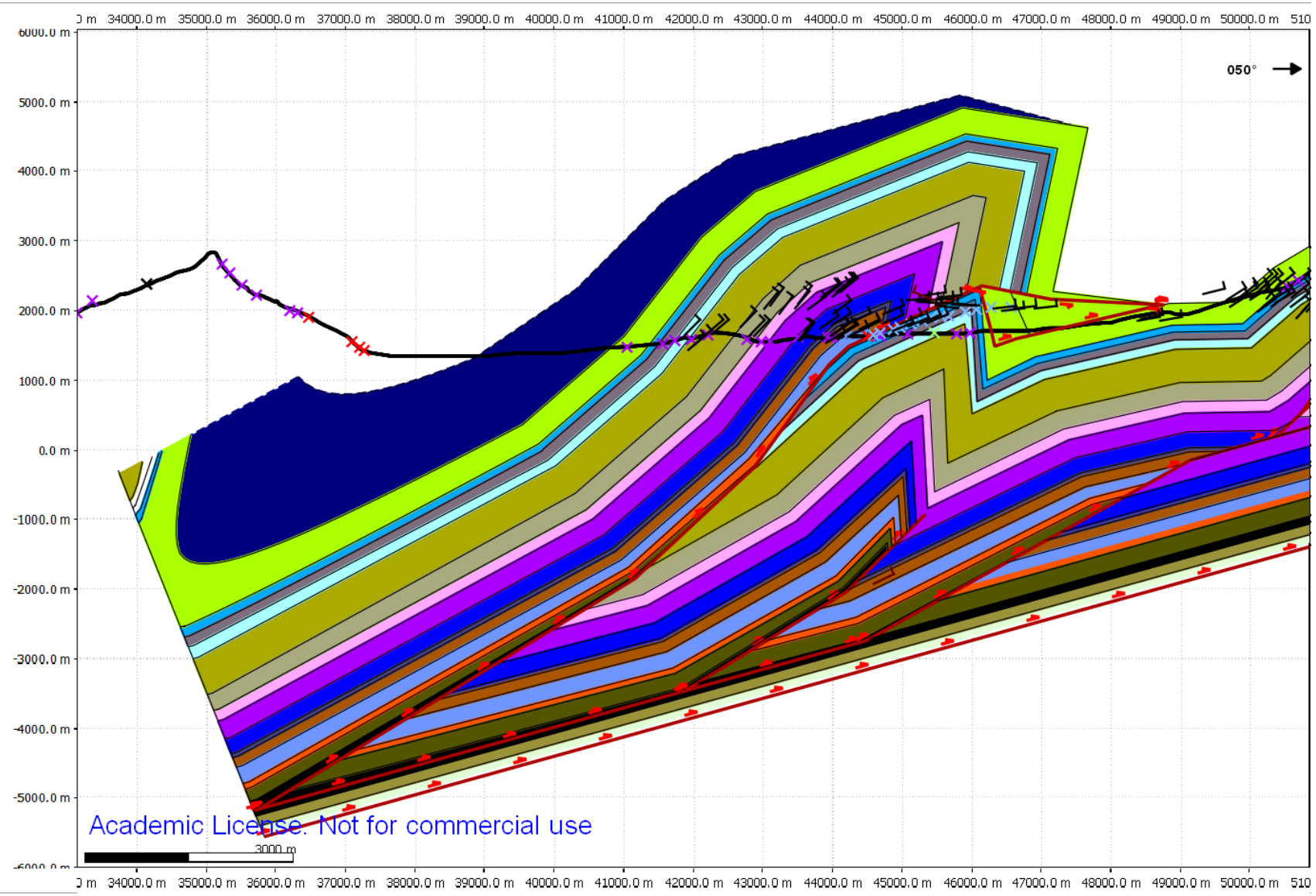
Observations:

-Overturned Anticline and Syncline pair

-The Inglismaldie Thrust is folded locally

-The Inglismaldie Thrust has horse tail splays locally

The Inglismaldie Thrust



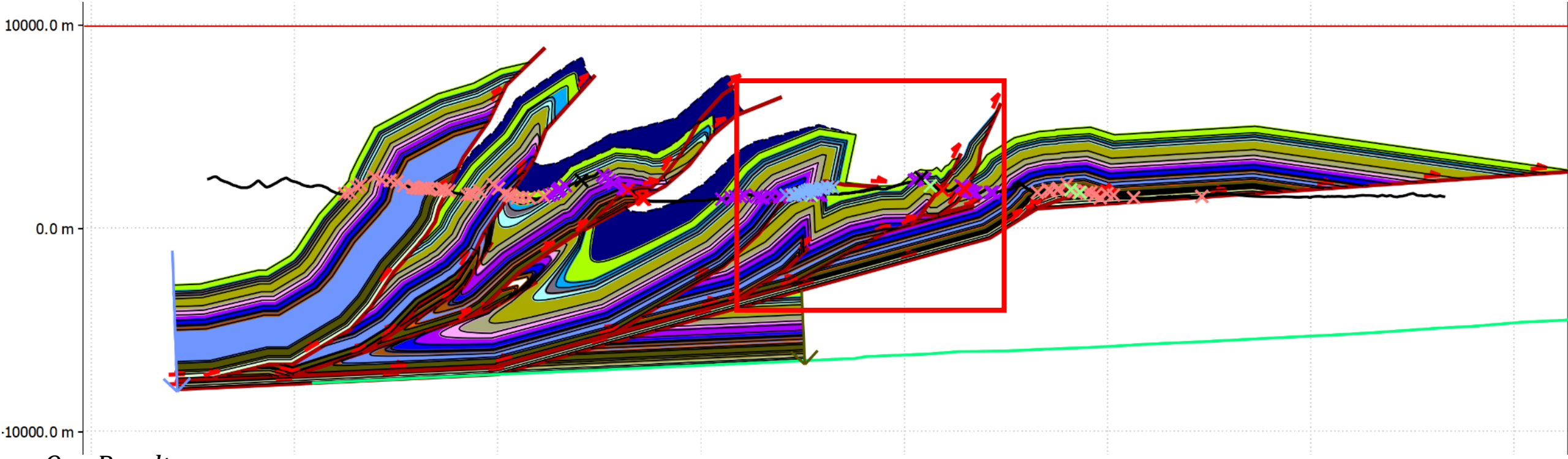
Interpretations:

The Inglsimadlie Thrust is locally modified by a fault-propagation fold in its footwall

The Inglismaldie and the structure in its footwall record break-forward imbrication.

The Inglismaldie Thrust and the footwall structure illustrate coeval timing (horse tail splays).

Area 2: The Inglismaldie Thrust



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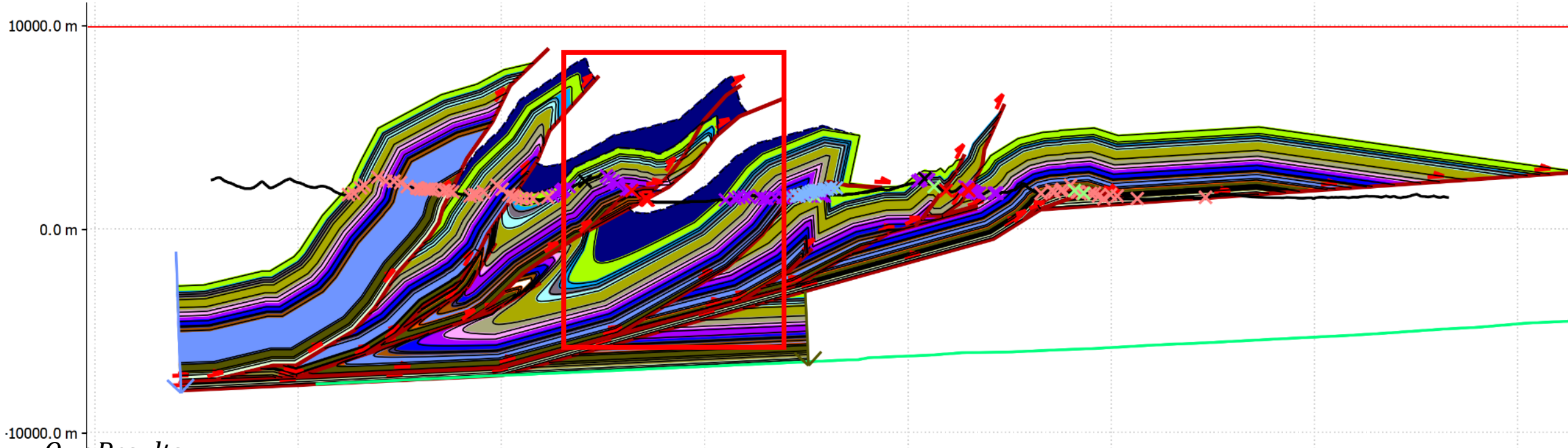
Area 3: The Rundle Thrust

Area 3: The Rundle Thrust



Our Results:

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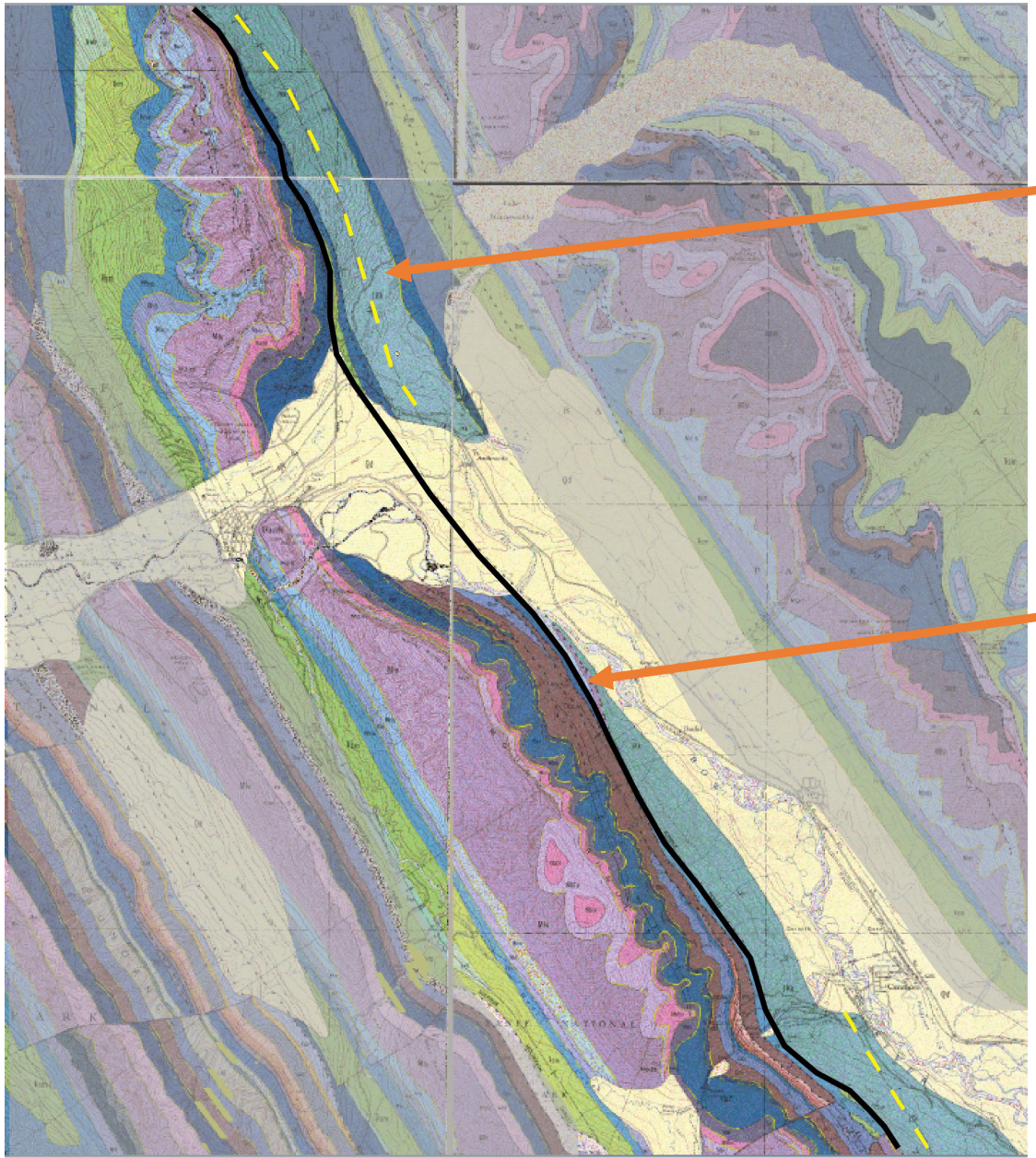
Thin Skinned Fold and Thrust Belt with Multiple Detachments → Area 1: The Costigan Thrust

Imbricate system made up of fault-bend and fault-propagation folds; break-forward thrusting sequence → Area 2: The Inglismalide Thrust

Breakthrough fault-propagation folds exhibit out-of-sequence thrusting → Area 3: The Rundle Thrust

Map Pattern of the Rundle Thrust



Rundle Thrust has steep forelimb in its footwall (Mount Allen Syncline)

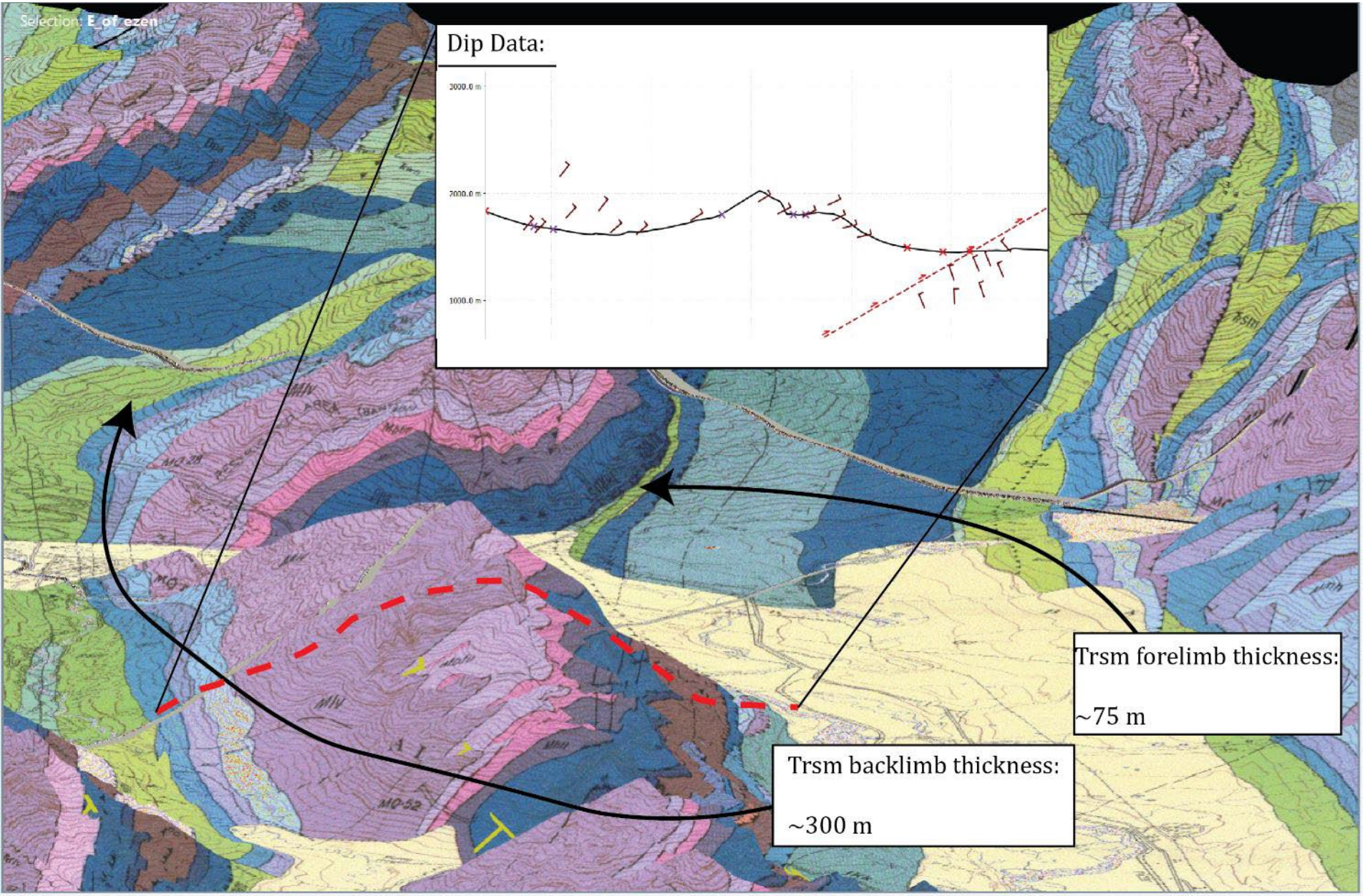
Mapped Rundle Thrust locally overtakes the syncline

Rundle Thrust Map Trace

Mount Allen Syncline Map Trace

Perspective View in next slide

Thinning Limbs in an Overturned Syncline



Steep, overturned, and thinned forelimb.

These are features that are common of fault-propagation folds.

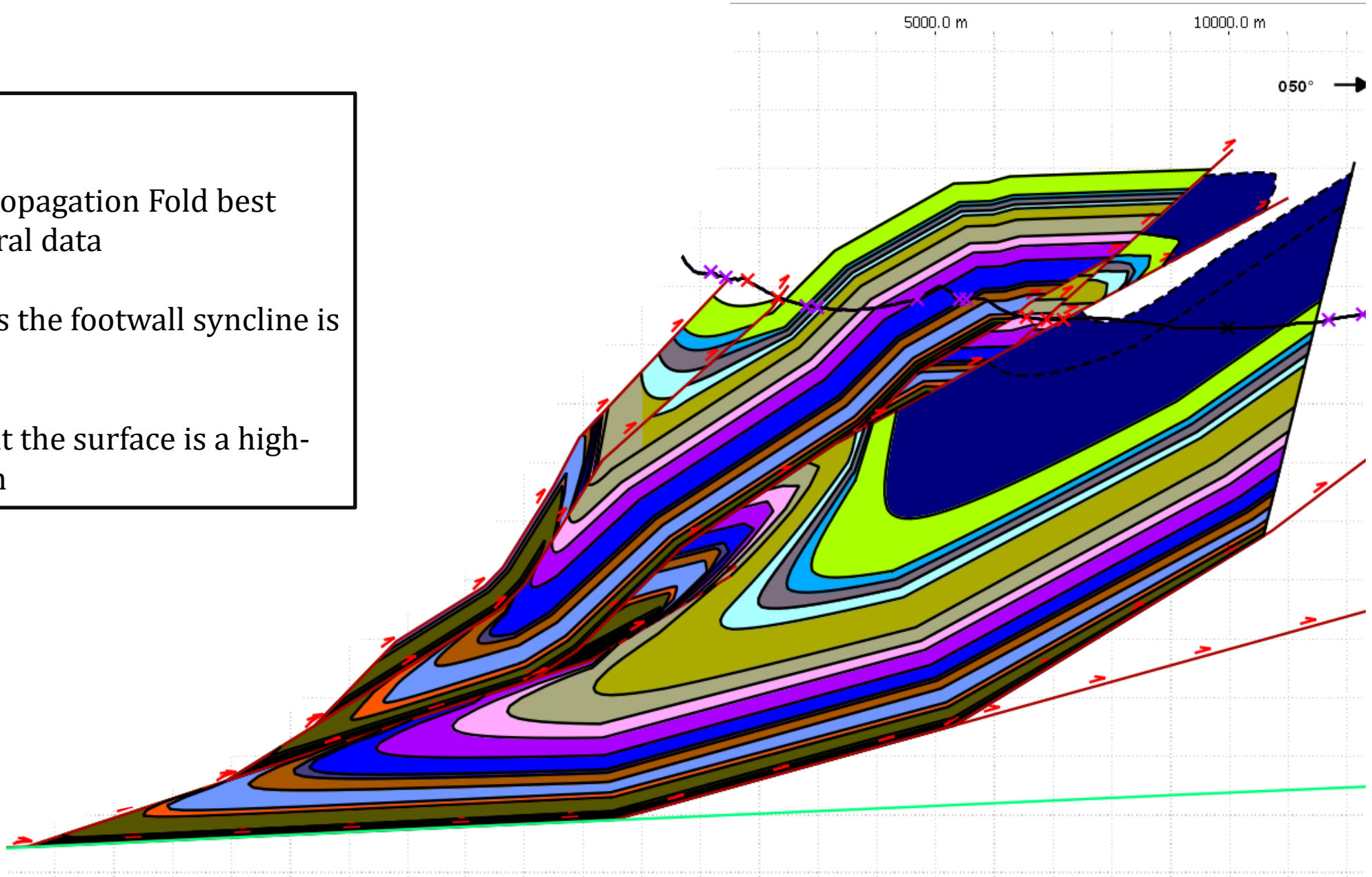
Kinematic Interpretation of the Rundle Thrust

Interpretation:

A Trishear Fault-Propagation Fold best models the structural data

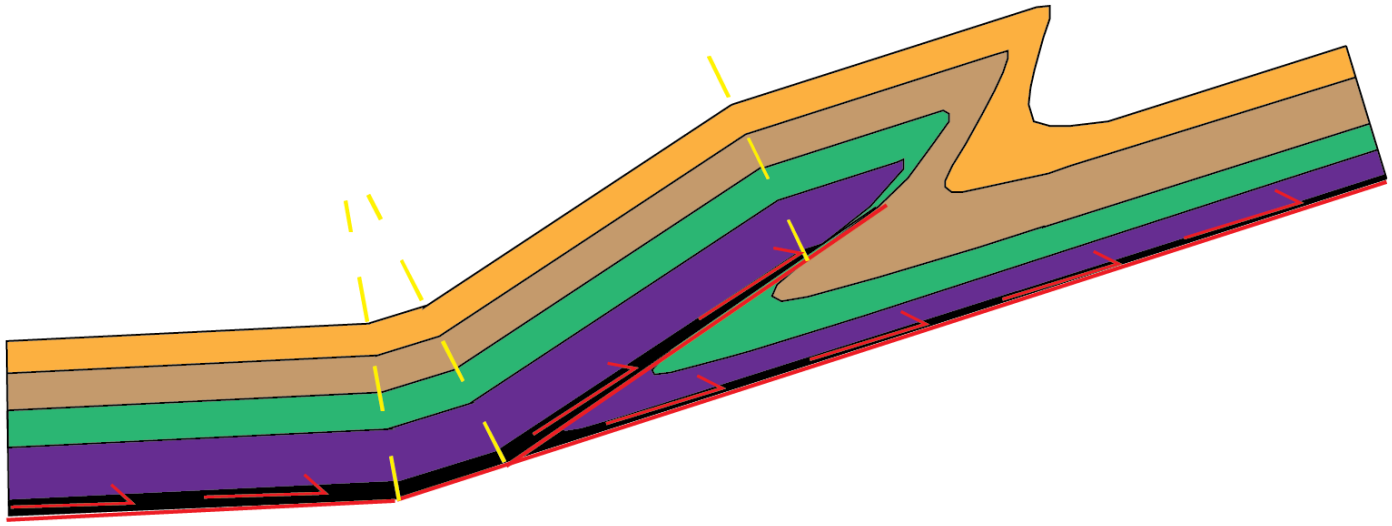
The fault that forms the footwall syncline is blind

The mapped fault at the surface is a high-angle breakthrough

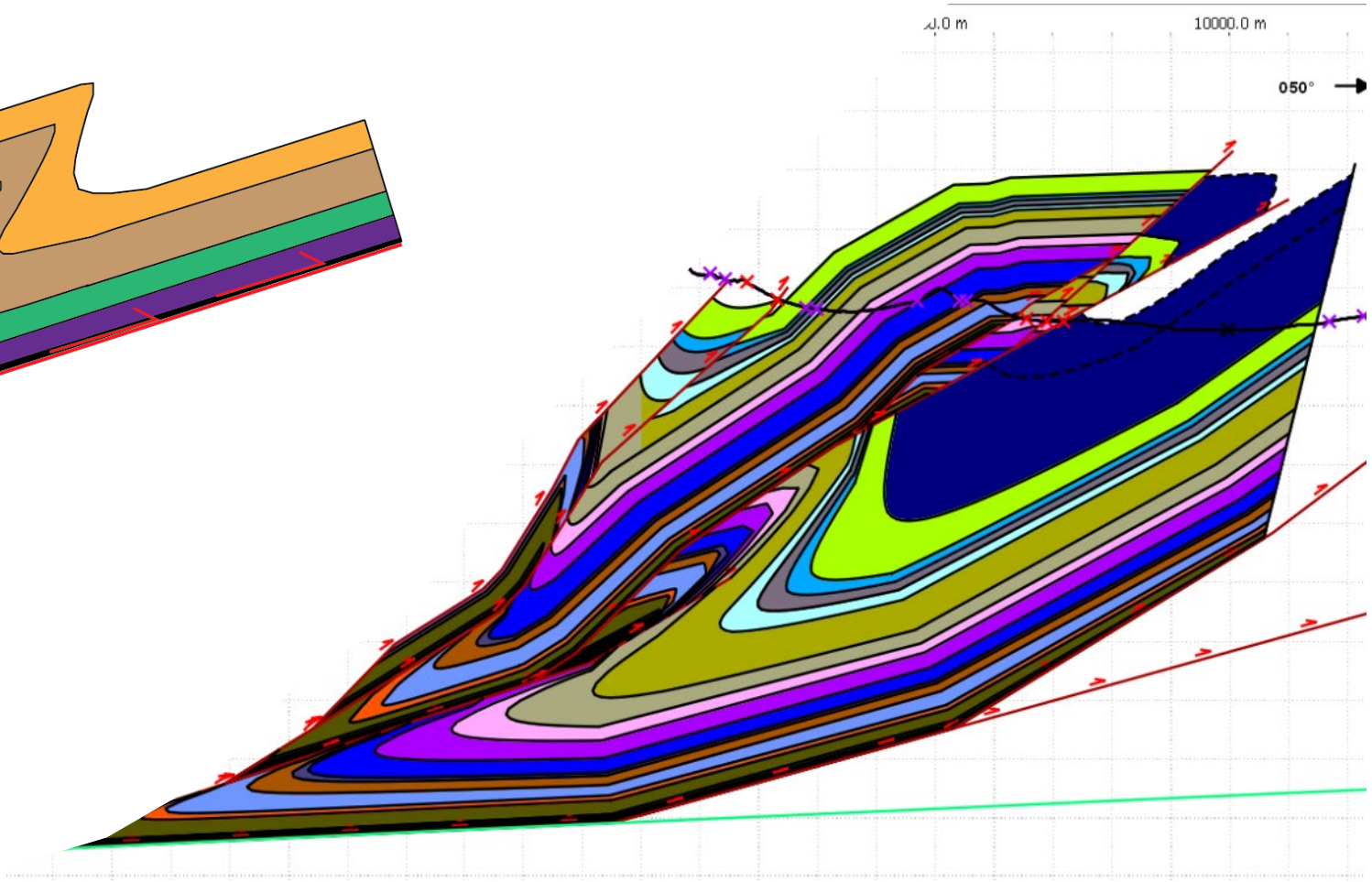


Kinematic Evolution of the Rundle Thrust

Kinematic Evolution:



Deformed State Cross Section:



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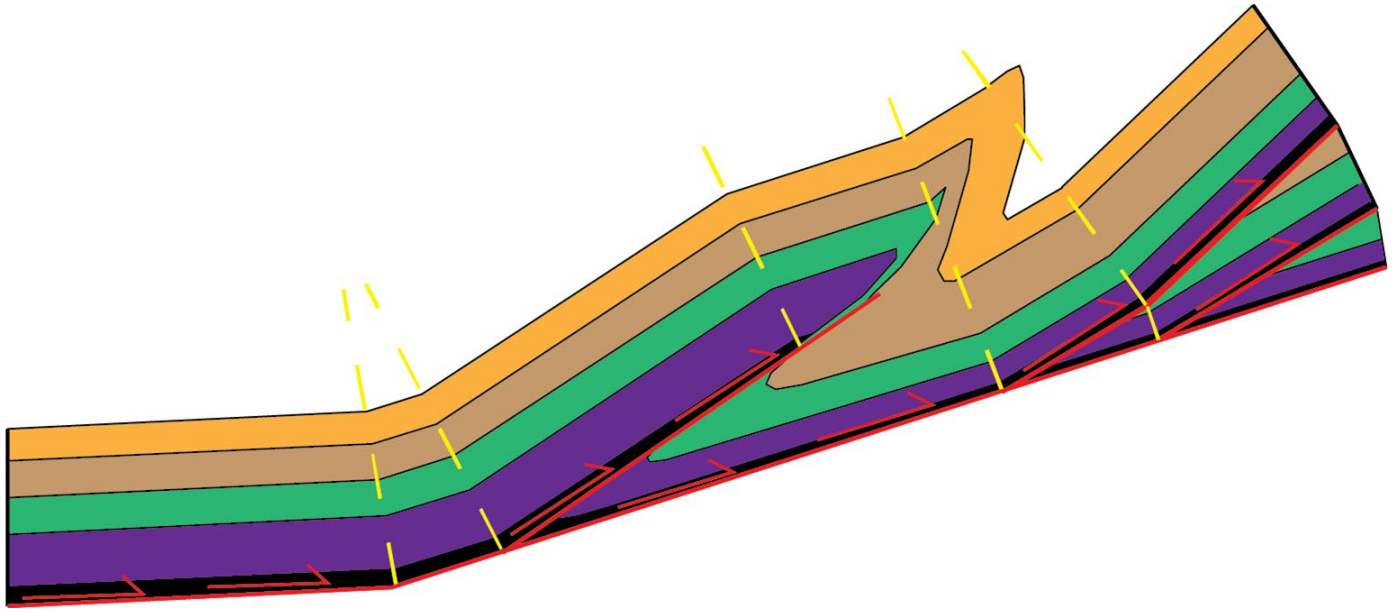
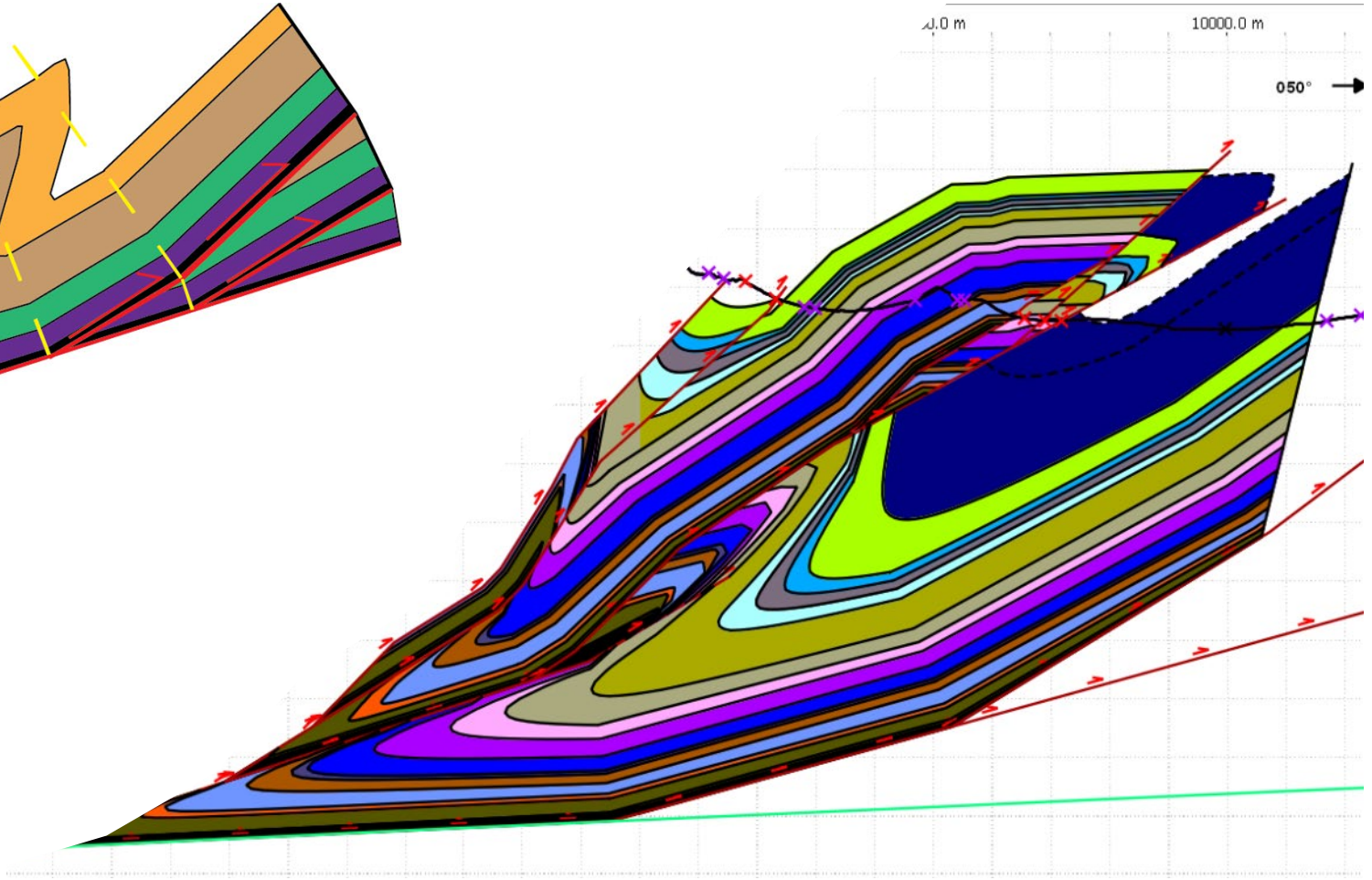


Deformed State Cross Section:



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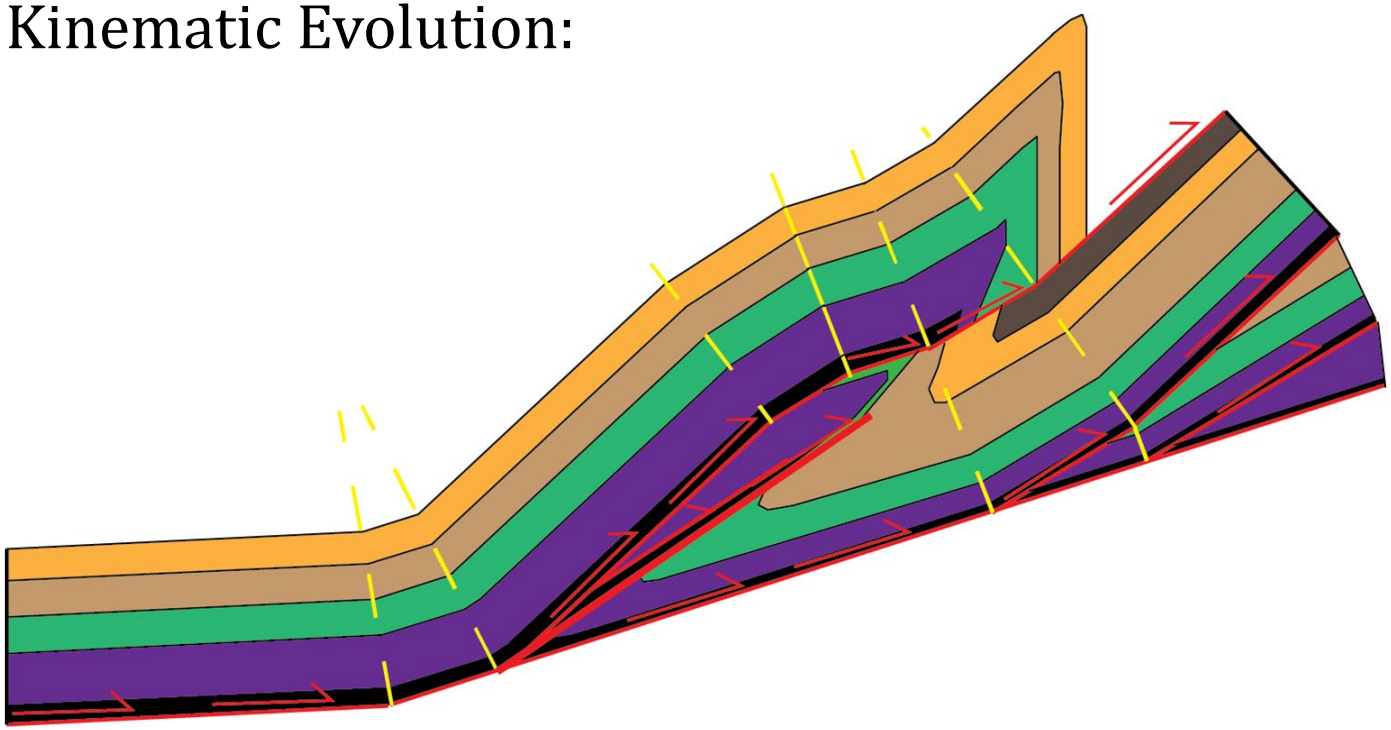
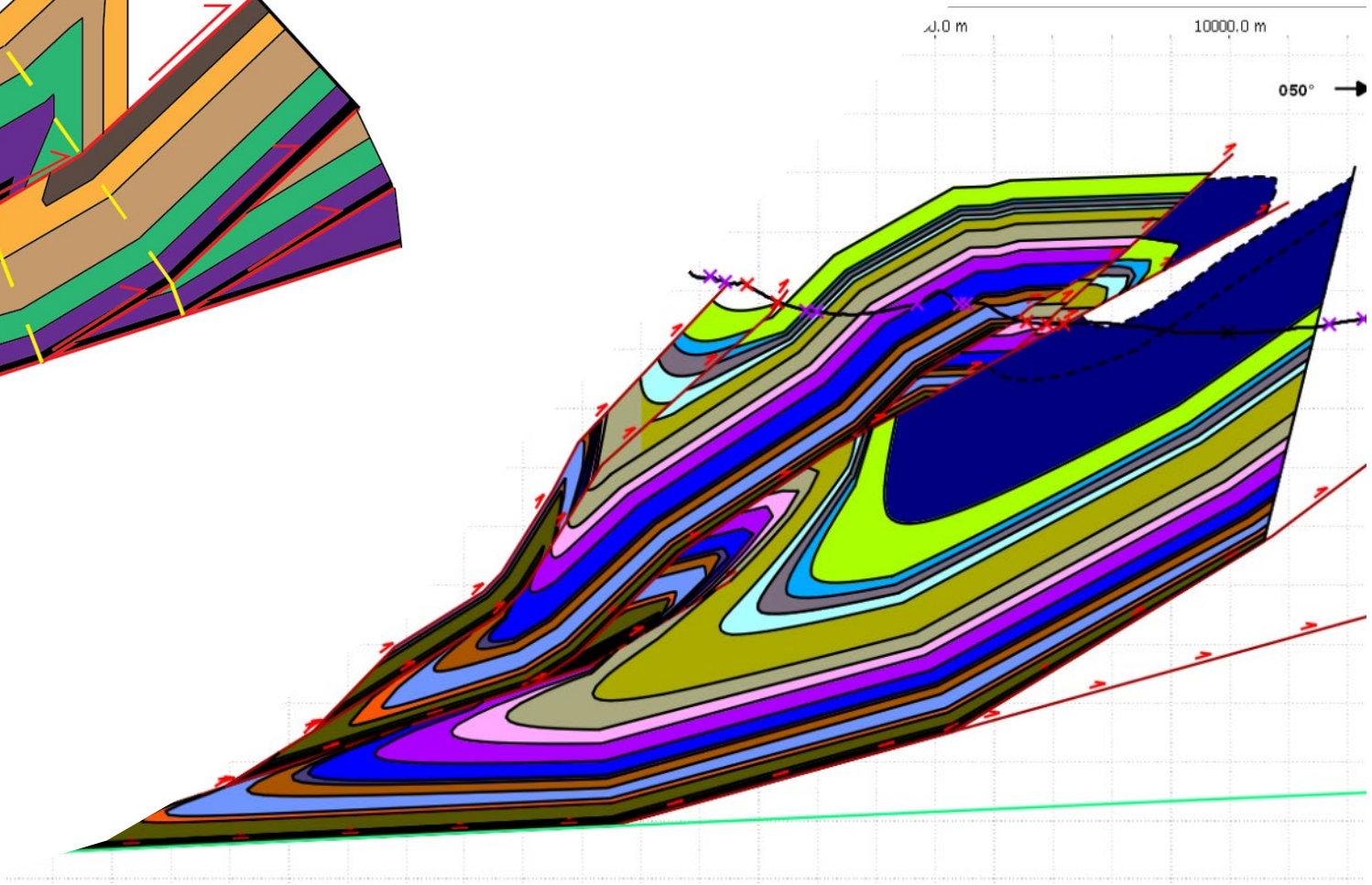
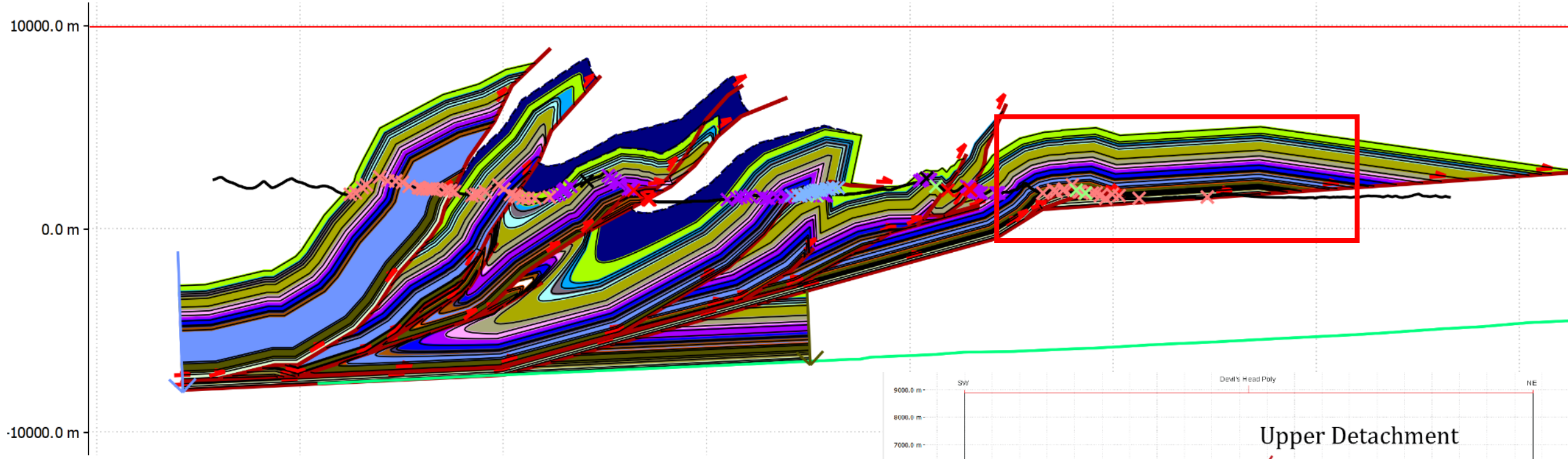
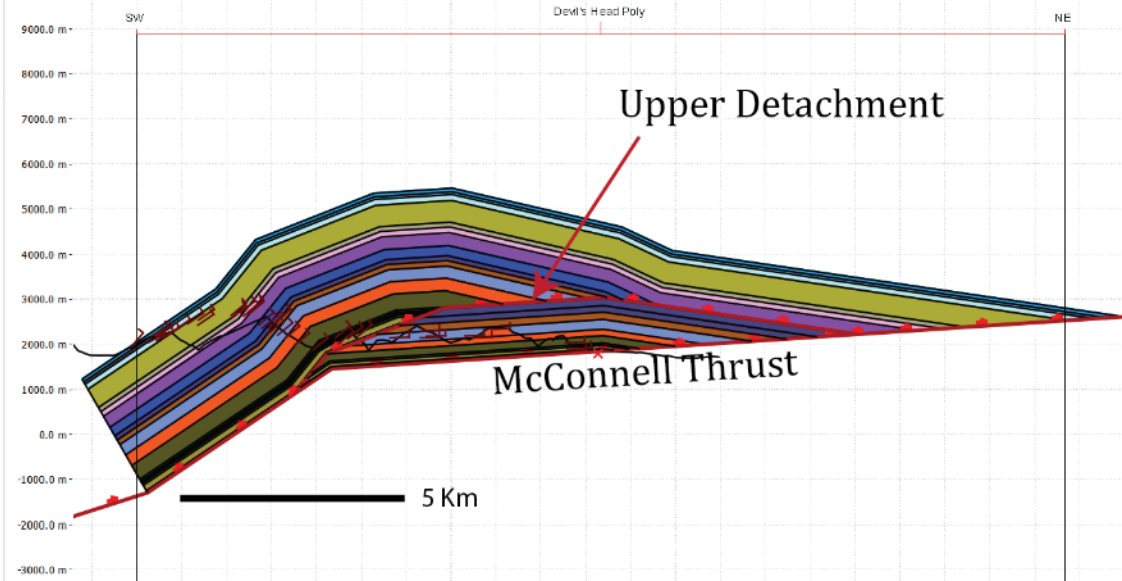


Deformed State Cross Section:

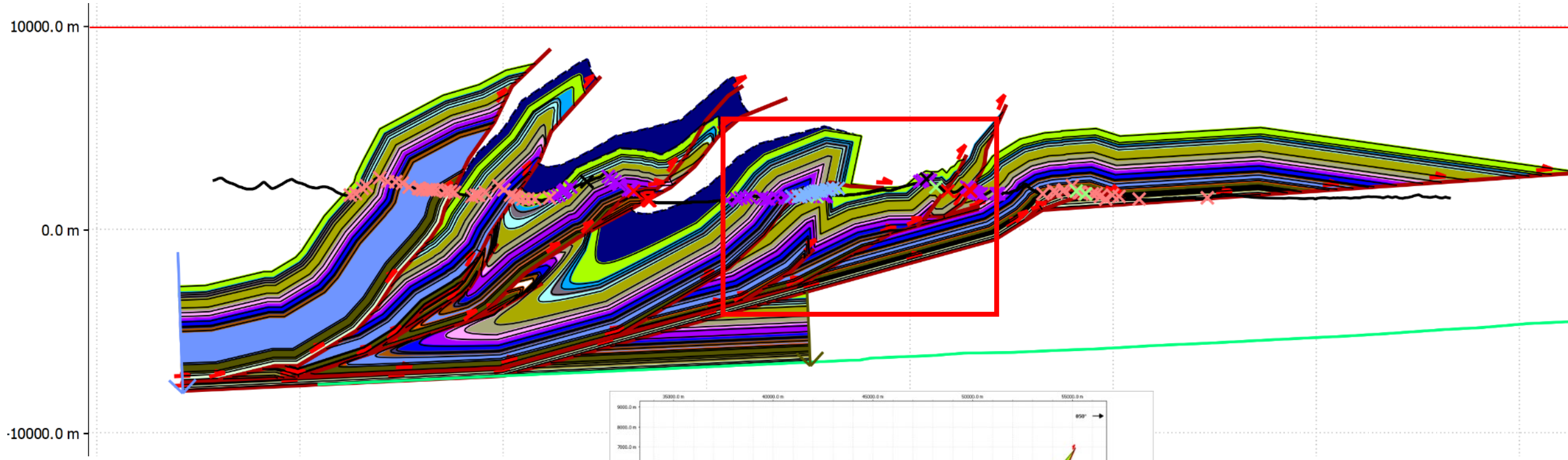


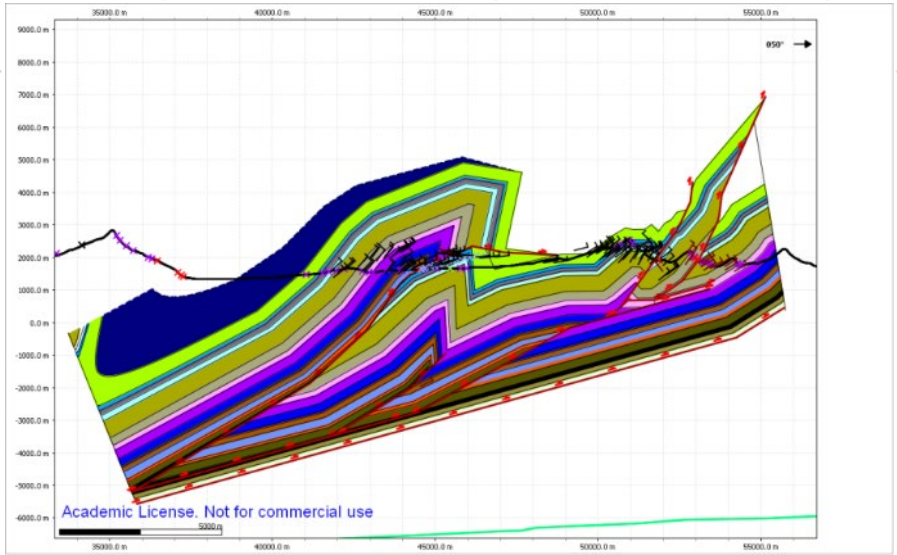
Case Study Takeaways:
Structural Styles of the Front Ranges





Case Study Takeaways:
Structural Styles of the Front Ranges





Case Study Takeaways:
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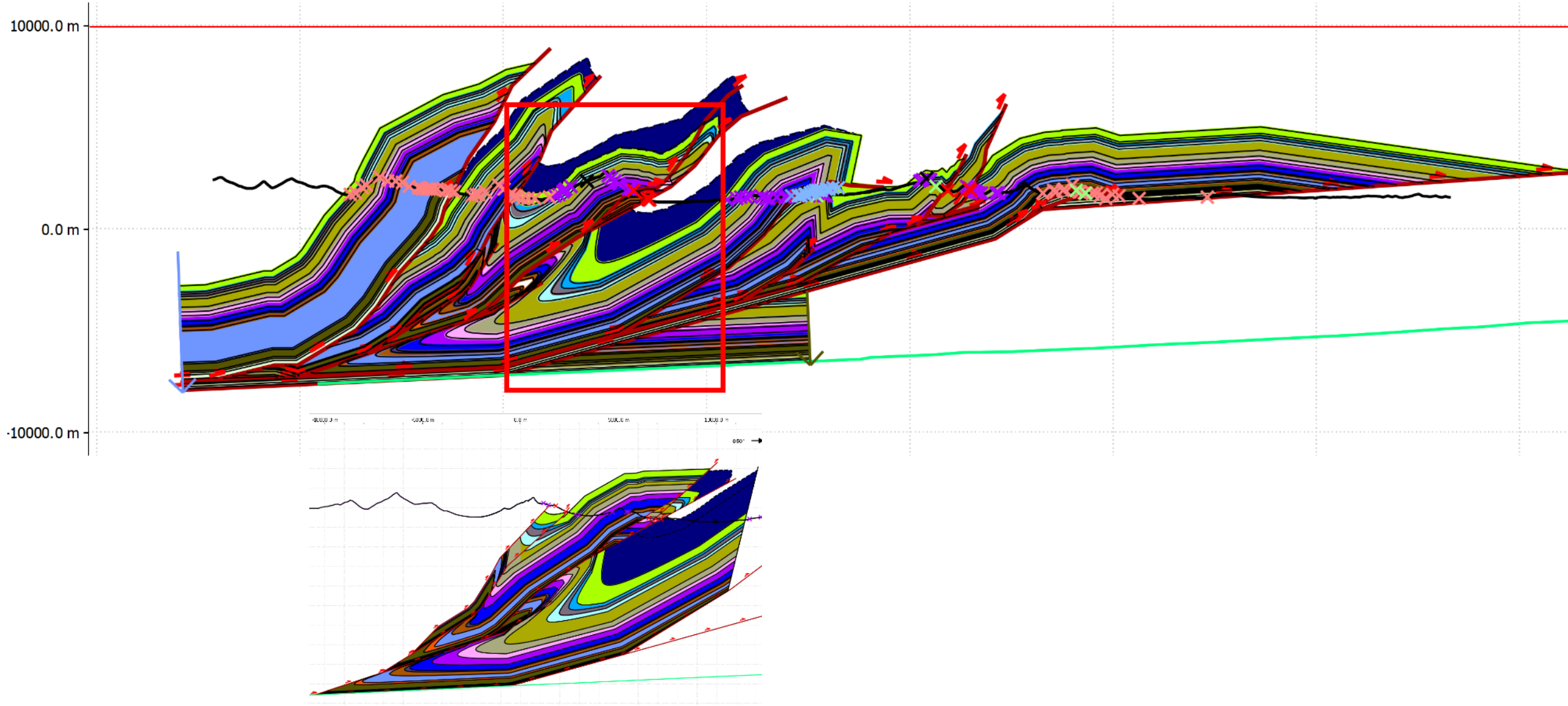

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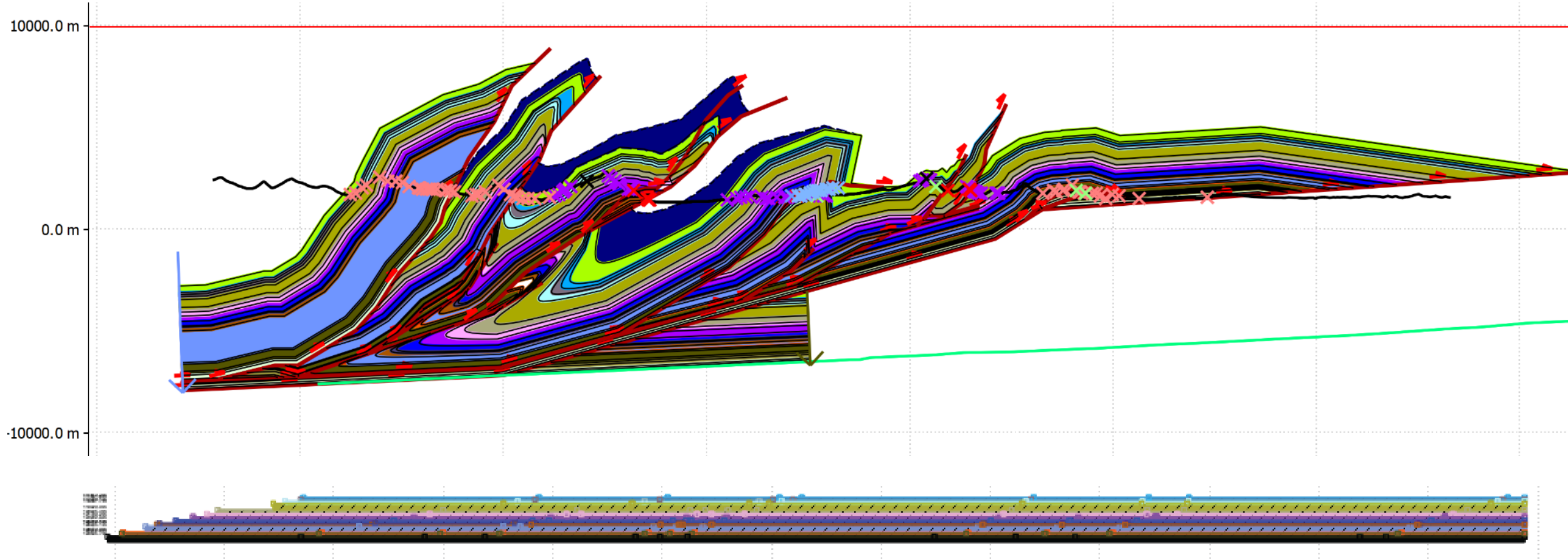
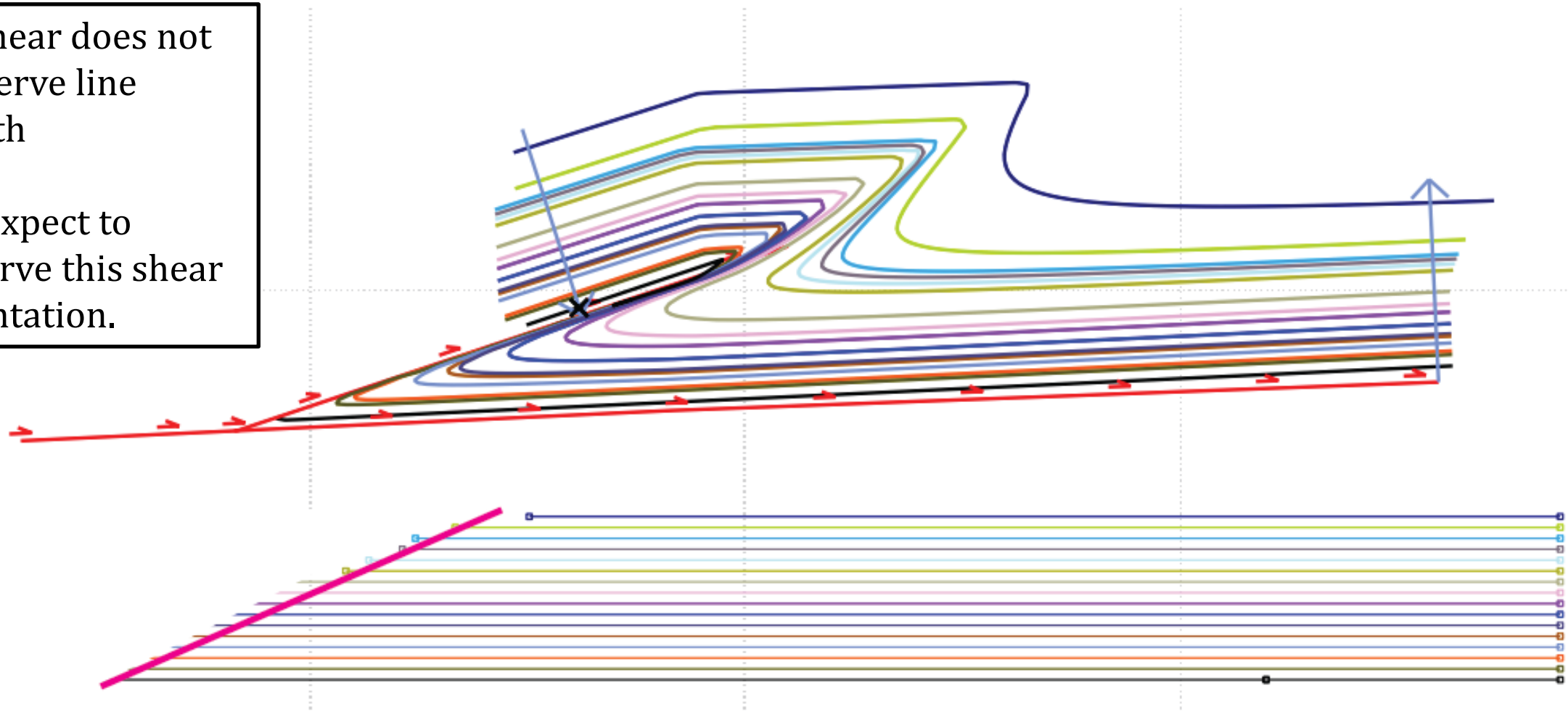


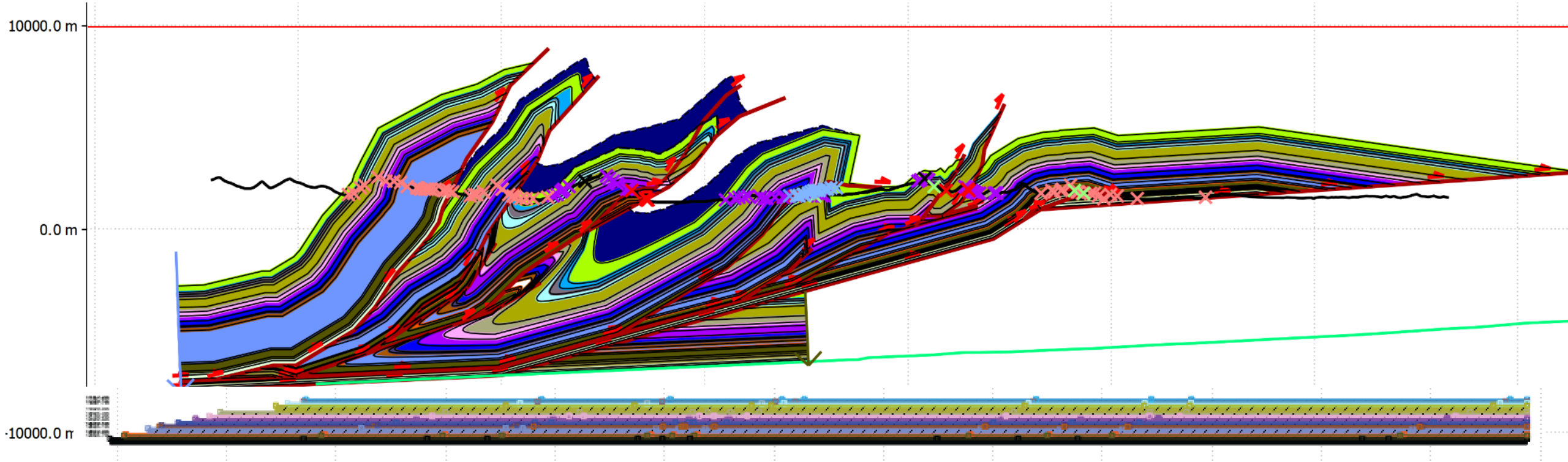
A note about balancing Trishear Fault Propagation Folds using line-length restoration techniques

Trishear does not preserve line length

We expect to observe this shear orientation.



A Kinematic & Line Length Balanced Model of the Front Ranges



Our Conclusions:

Thin-Skinned Fold and Thrust Belt with multiple detachments

Imbricate system made up of fault-bend, fault-propagation, and break-through fault-propagation folds

Heterogeneity in the timing of thrusting; both break-forward and break-backward (out of sequence) thrusting

77 km of shortening across the section

Questions?