Data Mining to Build Robust Chronostratigraphic Frameworks in the Western Interior Basin*

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Abstract

Geologic datasets are increasingly easier to access due to ongoing digitization efforts, yet utilization is still difficult due to the text- and figure-based nature of geologic data. Luckily, recent hardware and software advances enable geoscientists to integrate these datasets much faster and easier than before. To illustrate the power of data mining, a recommended workflow is presented which integrates newly-digitized USGS fossil localities with previously published datasets to create robust chronostratigraphic frameworks within the Western Interior Basin. The workflow comprises six stages: (1) data compilation, (2) duplication of published well log correlations, (3) subsurface-to-outcrop data integration, (4) standardization of interpretations, (5) data infilling, and (6) data expansion.

To begin, the user needs to define a stratigraphic unit-of-interest (UOI) and geographic area for the project. Through an extensive literature search, well log correlations, stratigraphic sections, and geologic maps which include the UOI are tabulated and integrated using spreadsheets and a business analytics software package. The data is then overlain to define an initial area-of-interest (AOI) and a subsurface geological model is created by duplicating published well log correlations. These correlations are then integrated with outcrop data by creating a cross section grid tied to stratigraphic sections. Geologic maps are utilized simultaneously to guide well log correlations, and ammonites are employed to troubleshoot incorrect correlations and standardize interpretations. Once a satisfactory answer has been reached, the AOI is infilled with additional data and expanded. Although the workflow is not inherently novel, it defines a systematic approach to data mining within the Western Interior Basin that highlights contradictory subsurface correlations and stratigraphic nomenclature. To demonstrate the process, a case study is presented which applies the recommended workflow to the Castlegate Member, Piceance Basin, Colorado.

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Bryan McDowell*, Piret Plink-Bjorklund

September 16, 2019

The Problem

- Geologic datasets are increasingly easier to access due to ongoing digitization efforts by:
  - Geologic surveys
  - Professional societies
  - Regulatory agencies
  - Academia

- Although more accessible, utilization is still difficult due to the inherent nature of geologic data:
  - Heavily text-based
  - Commonly embedded within figures
  - Rarely tabulated

The Problem (cont.)

- As researchers, we are often left with highly-fragmented datasets of varying quality/content that are not easily compiled/manipulated

- As a result, when working in highly-researched areas, such as the Rocky Mountains, we are often *"…drowning in information but starved for knowledge."* (Naisbit, 1982)

- Luckily, advances in business analytics tools enable geoscientists to integrate data much faster/easier
  - Examples:
    - TIBCO Spotfire, Tableau, Microsoft PowerBI, etc.
  - However, these tools are slowly being adopted by the community

Data Mining

- We should leverage what is already available to:
  1. Save time/money (e.g., don't reinvent the wheel)
  2. Promote integration with other studies

- To illustrate the point, we will present a workflow to data mine ammonite localities to build chronostratigraphic frameworks in the WIB
  - Please note:
    - This is not rocket science! (sorry… ☹)
    - It's a logical methodology to highlight errors

Workflow

1. Data compilation
2. Duplication of published well log correlations
3. Subsurface-to-outcrop data integration
4. Standardization of interpretations
5. Areal infilling
6. Areal expansion

Required Software

- Spreadsheet software to compile/edit data
  - E.g., Microsoft Excel, SQL
- Business analytics software to link/visualize data
  - E.g., TIBCO Spotfire or Tableau
- Subsurface correlation software for well log correlations
  - E.g., IHS Markit Petra, Schlumberger Petrel, etc.

Case Study

Castlegate Sandstone, Piceance Basin, Colorado

Castlegate Sandstone

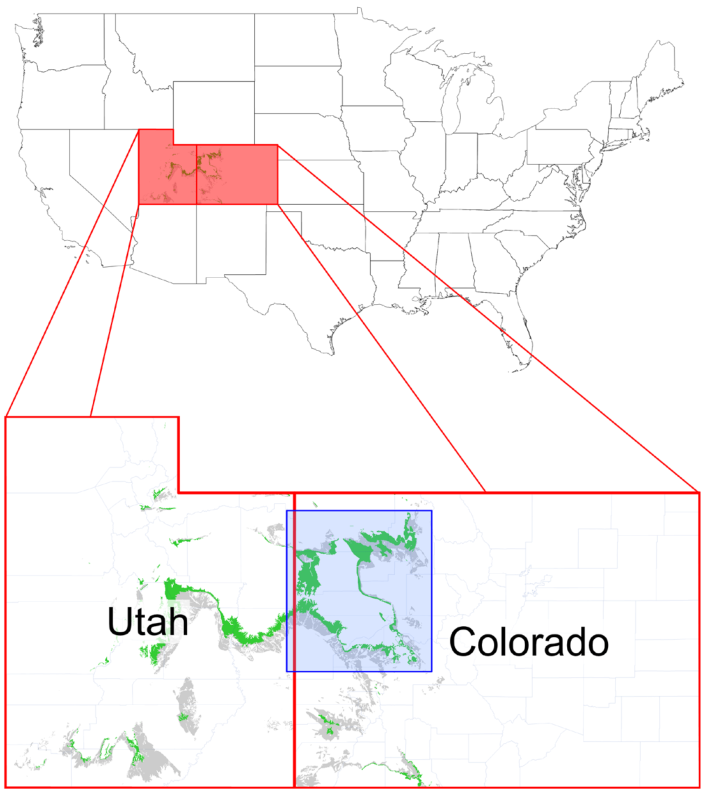
- Late Cretaceous (Campanian) stratigraphic unit
  - Focus of extensive sequence stratigraphic studies:
    - Van Wagoner et al. (1990); Van Wagoner (1995); Yoshida et al. (1996); McLaurin & Steel (2000); Miall & Arush (2000)
- Found in outcrop in two areas:
  - Northern area
    - Margins of the NE Uinta-NW Piceance basins
  - Southern area
    - Margins of the SE Uinta-SW Piceance basins

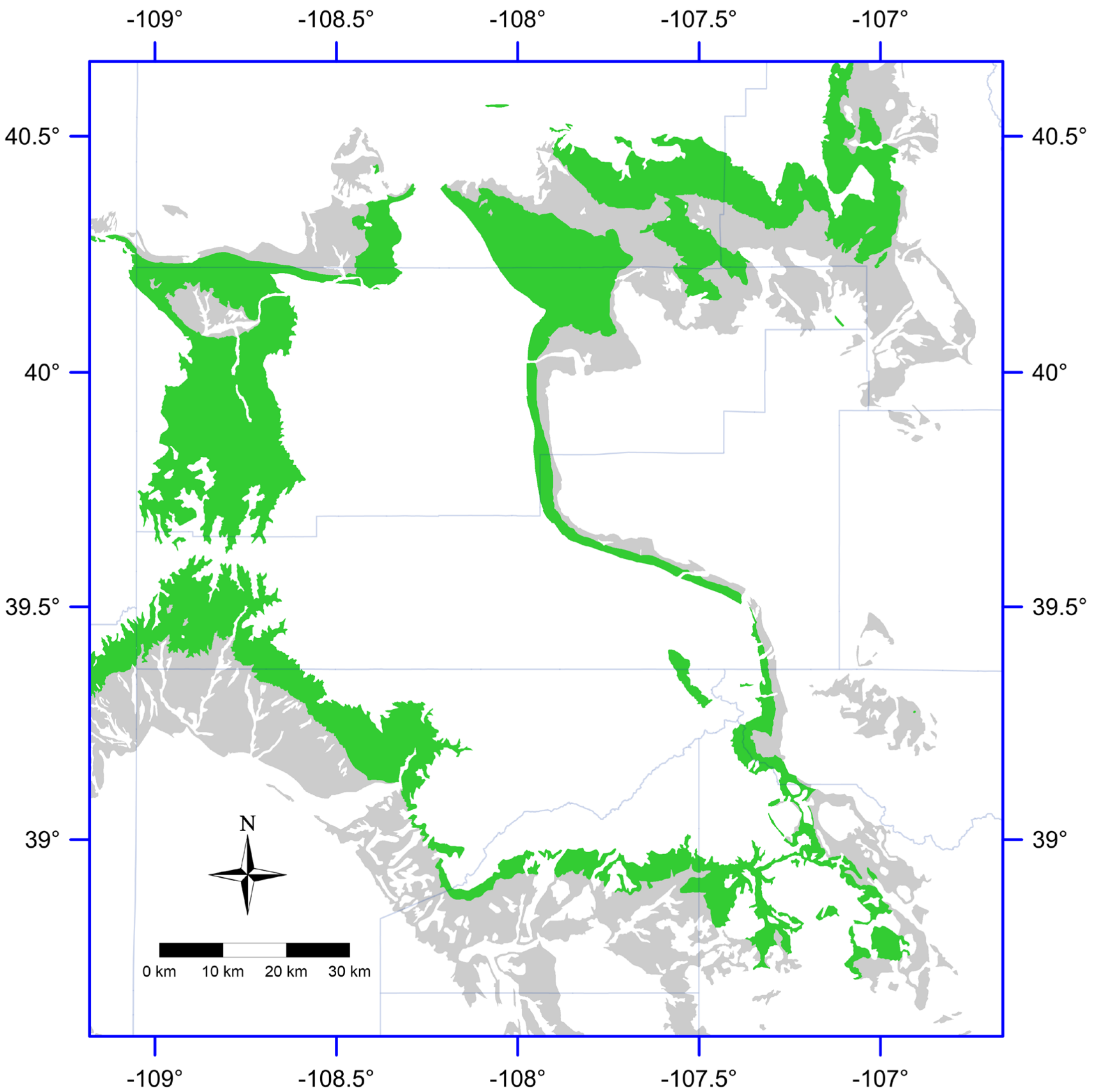
Castlegate Sandstone (cont.)

- The transition from fluvial to marine depositional environments has been widely studied
  - However, these studies usually stop where the sandstone facies end

- Age-equivalent mudstones and siltstones are present throughout the basin but are difficult to correlate

Study Area





Green = Mesverde Group outcrops

Gray = Mancos Group outcrops

Workflow

1. **Data compilation**
2. Duplication of published well log correlations
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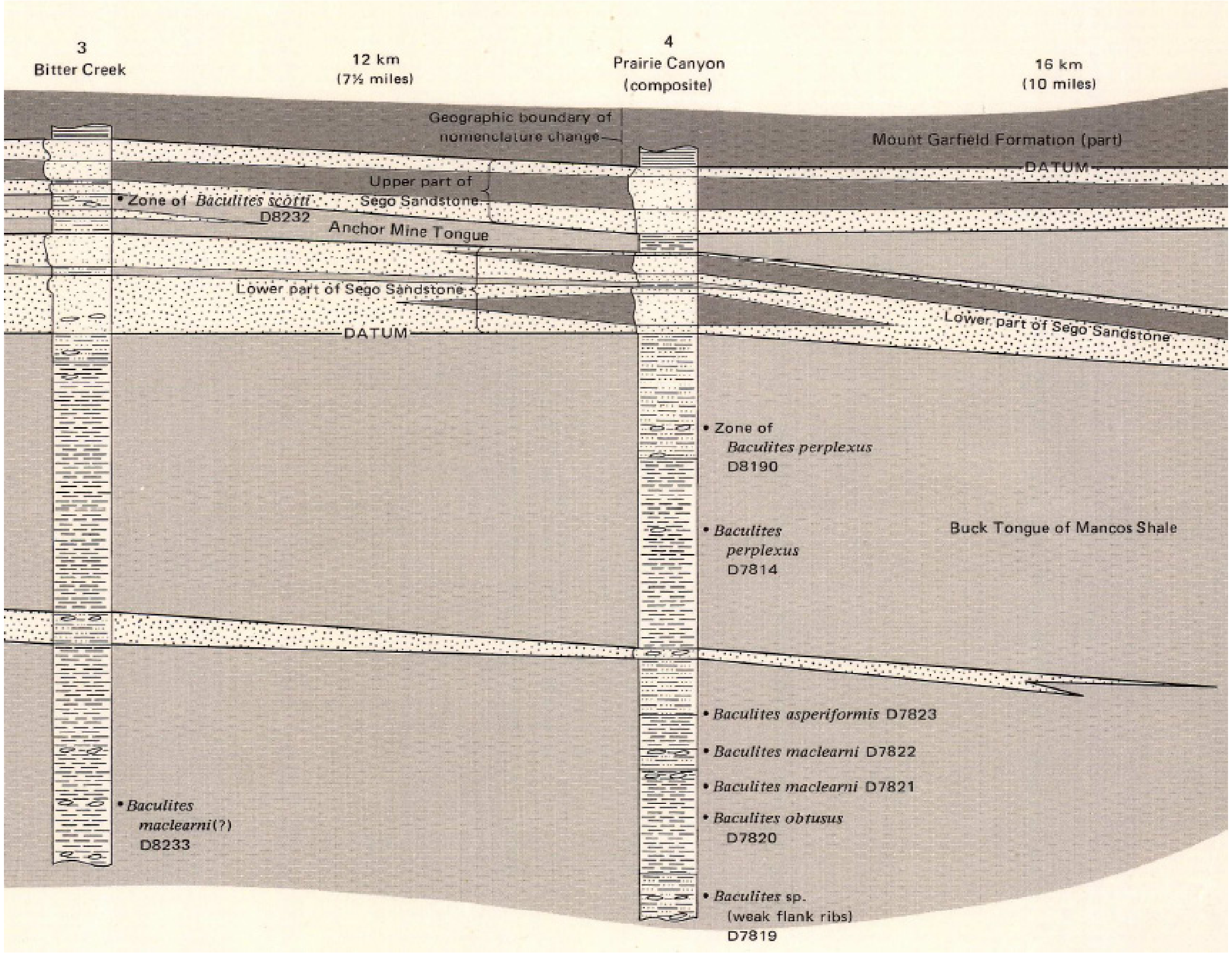
6. Areal expansion

Data Compilation

- Literature search for:
  - Ammonite localities
  - Stratigraphic sections
  - Subsurface correlations
  - Geologic maps

- Compile/convert text- and figure-based data into tables
  - Microsoft Excel is a simple/cheap option for data tables
  - TIBCO Spotfire or Tableau is great for integrating data for dynamic visualizations

Figure-based Data



From Gill & Hail (1975)

Stratigraphic Section Index

	A	E	F	G	H	I	J	K	N	O
1	Author(s)	Strat Section	State	County	Section	Township	Range	Qtr Sec	Latitude	Longitude
94	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Utah	Grand	9	17S	25E	W1/2	39.34287	-109.15914
95	Gill & Hail (1975)	Bitter Creek (below top Castlegate)	Utah	Grand	16	17S	25E	E1/2	39.32846	-109.14974
109	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Colorado	Garfield	30	7S	104W	SW1/4	39.42125	-109.03631
110	Gill & Hail (1975)	Prairie Canyon (composite) (below top Castlegate)	Colorado	Garfield	18	8S	104W	NE1/4	39.37135	-109.02574

Geologic Unit Index

	A	B	C	D
1	Author(s)	Strat Section	Reported Geologic Unit	Interpreted Geologic Unit
520	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Neslen Formation	Neslen Fm
521	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Upper part of Sego Sandstone	Upper Sego Sandstone
522	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Anchor Mine Tongue of Mancos Shale	Anchor Mine Tongue
523	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Lower part of Sego Sandstone	Lower Sego Sandstone
524	Gill & Hail (1975)	Bitter Creek (above top Castlegate)	Buck Tongue of Mancos Shale	Buck Tongue
526	Gill & Hail (1975)	Bitter Creek (below top Castlegate)	Main body of Mancos Shale (part)	Mancos Shale (sub-Castlegate)
672	Gill & Hail (1975)	Bitter Creek (below top Castlegate)	Castlegate Sandstone	Castlegate Sandstone
673	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Mount Garfield Formation (part)	Iles Fm
674	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Upper part of Sego Sandstone	Upper Sego Sandstone
675	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Anchor Mine Tongue of Mancos Shale	Anchor Mine Tongue
676	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Lower part of Sego Sandstone	Lower Sego Sandstone
678	Gill & Hail (1975)	Prairie Canyon (composite) (above top Castlegate)	Buck Tongue of Mancos Shale	Buck Tongue
987	Gill & Hail (1975)	Prairie Canyon (composite) (below top Castlegate)	Main body of Mancos Shale (part)	Mancos Shale (sub-Castlegate)
1012	Gill & Hail (1975)	Prairie Canyon (composite) (below top Castlegate)	Castlegate Sandstone	Castlegate Sandstone

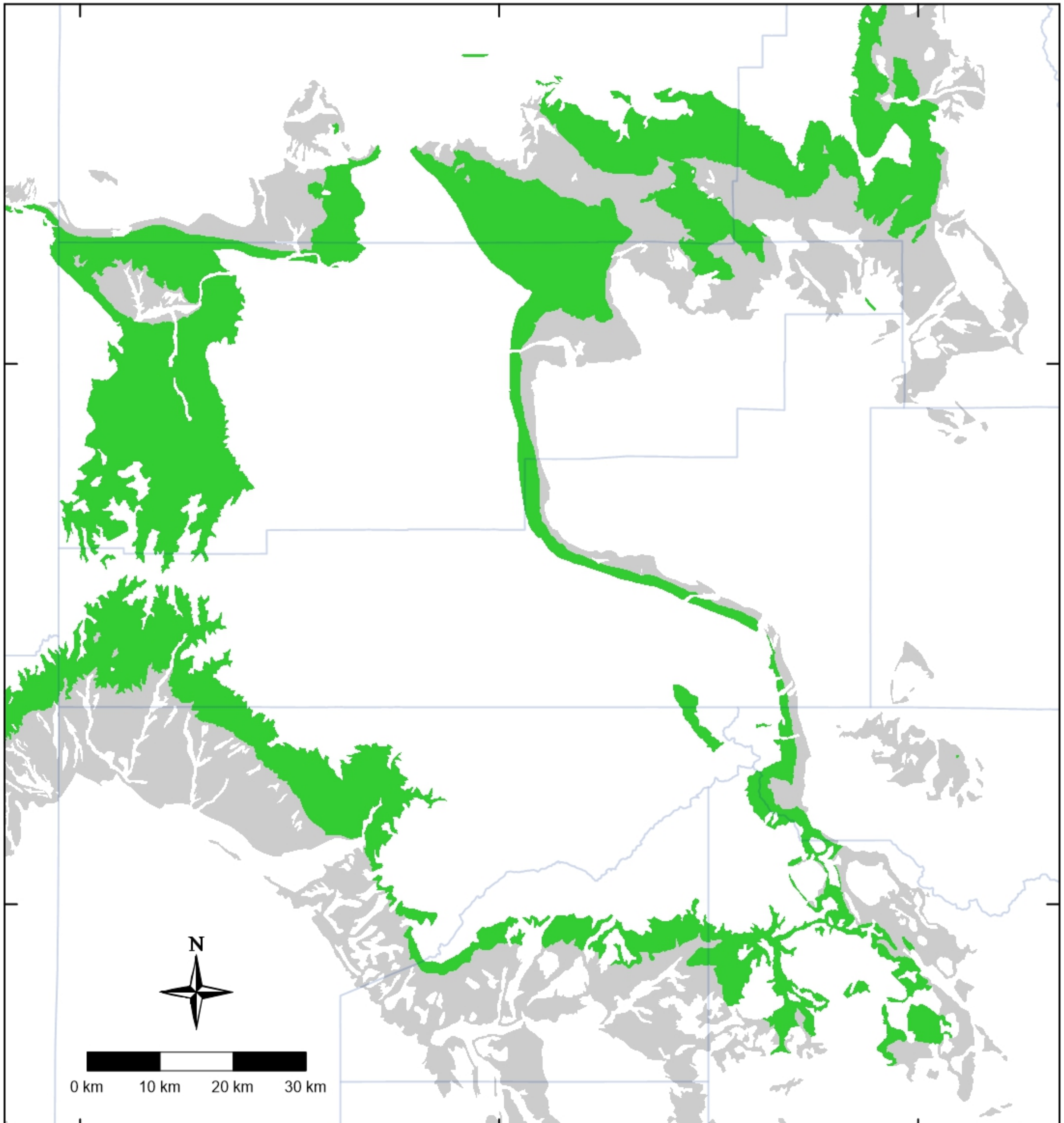
Data Tables

1. *Ammonite Fossil Locality Index*

2. *Stratigraphic Section Index*
    - And its corresponding *Stratigraphic Unit Index*

3. *Subsurface Correlation Index*
    - And its corresponding *Stratigraphic Unit Index*

4. *Geologic Map Index*
    - And its corresponding *Stratigraphic Unit Index*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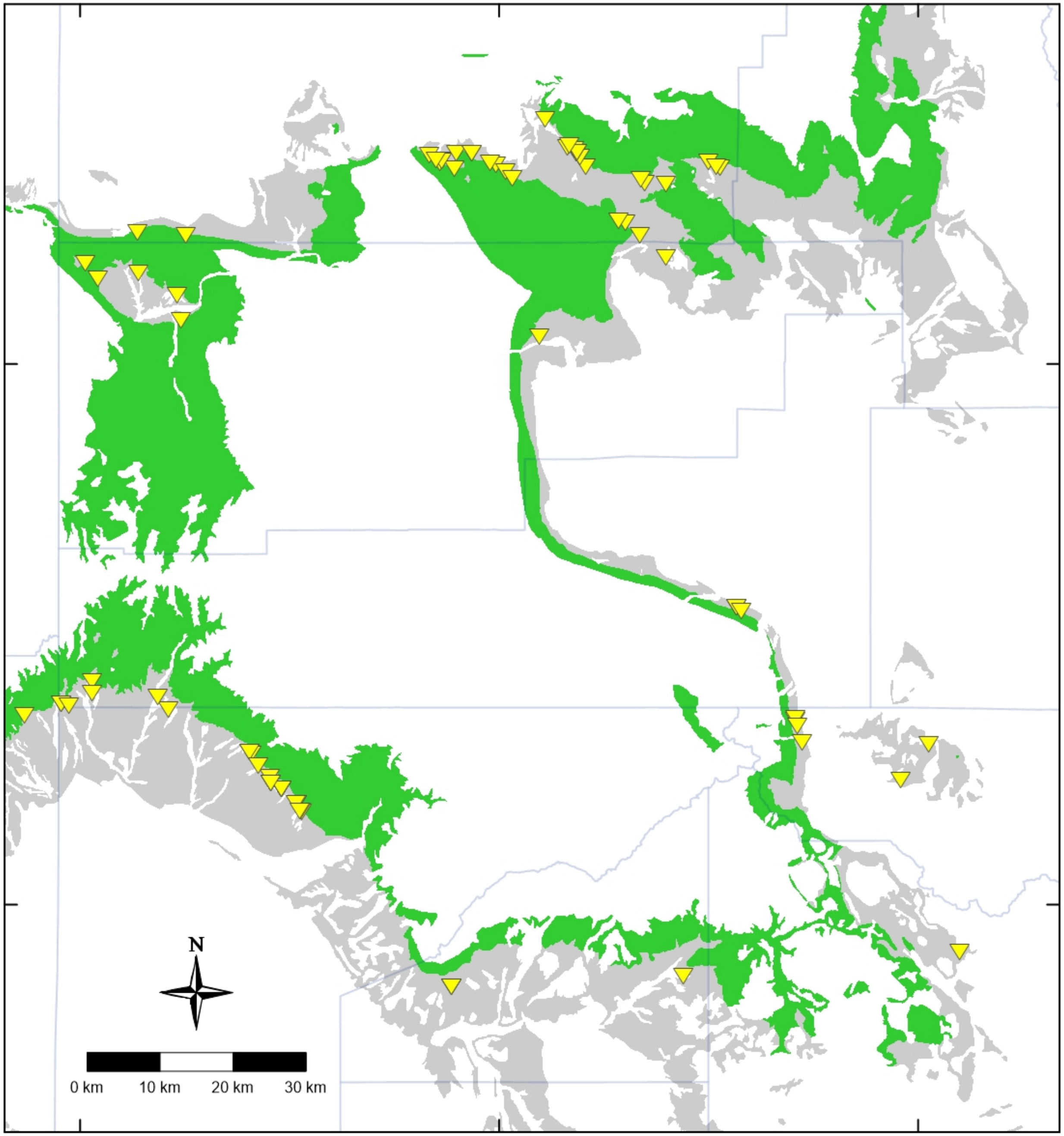
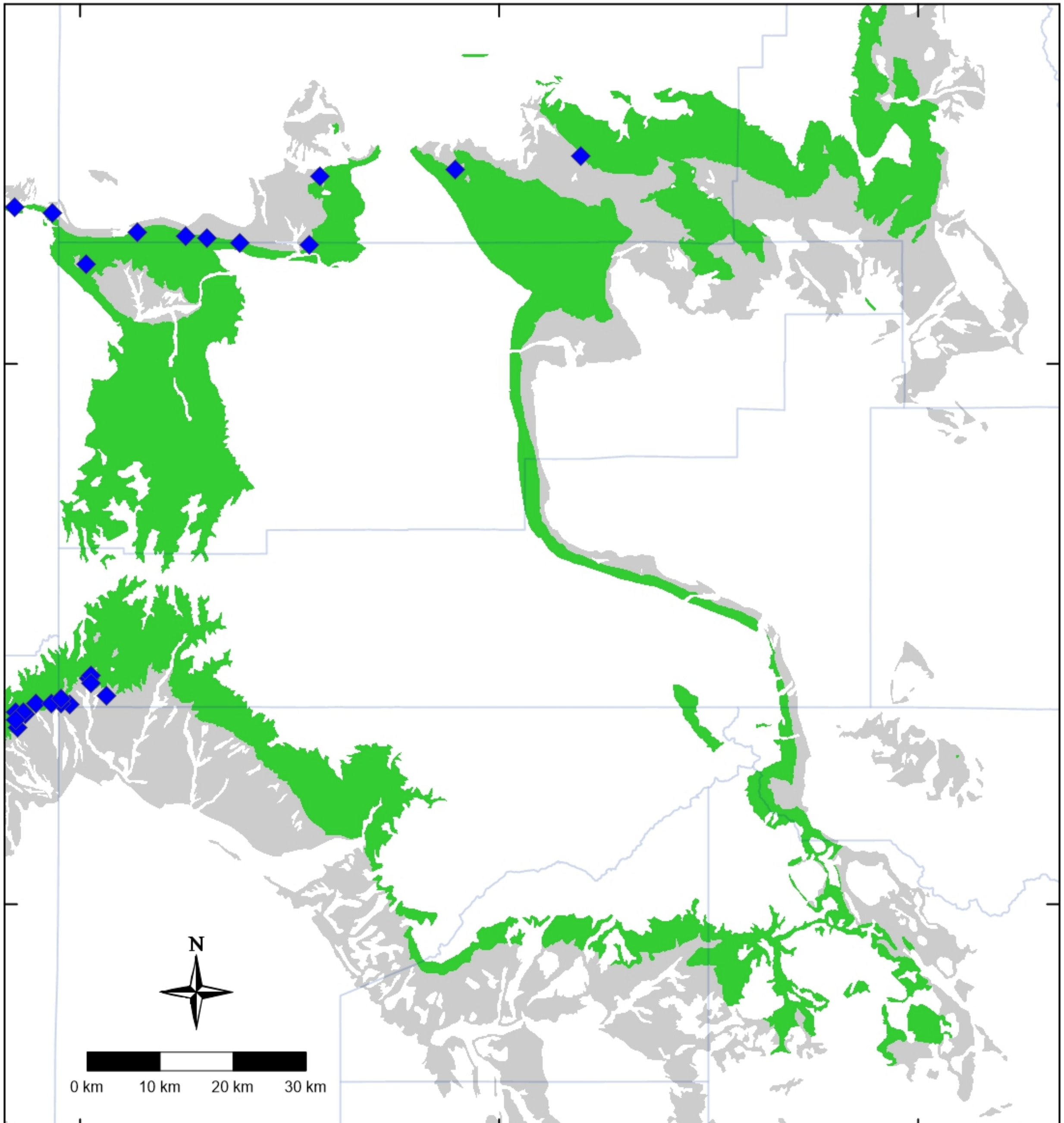


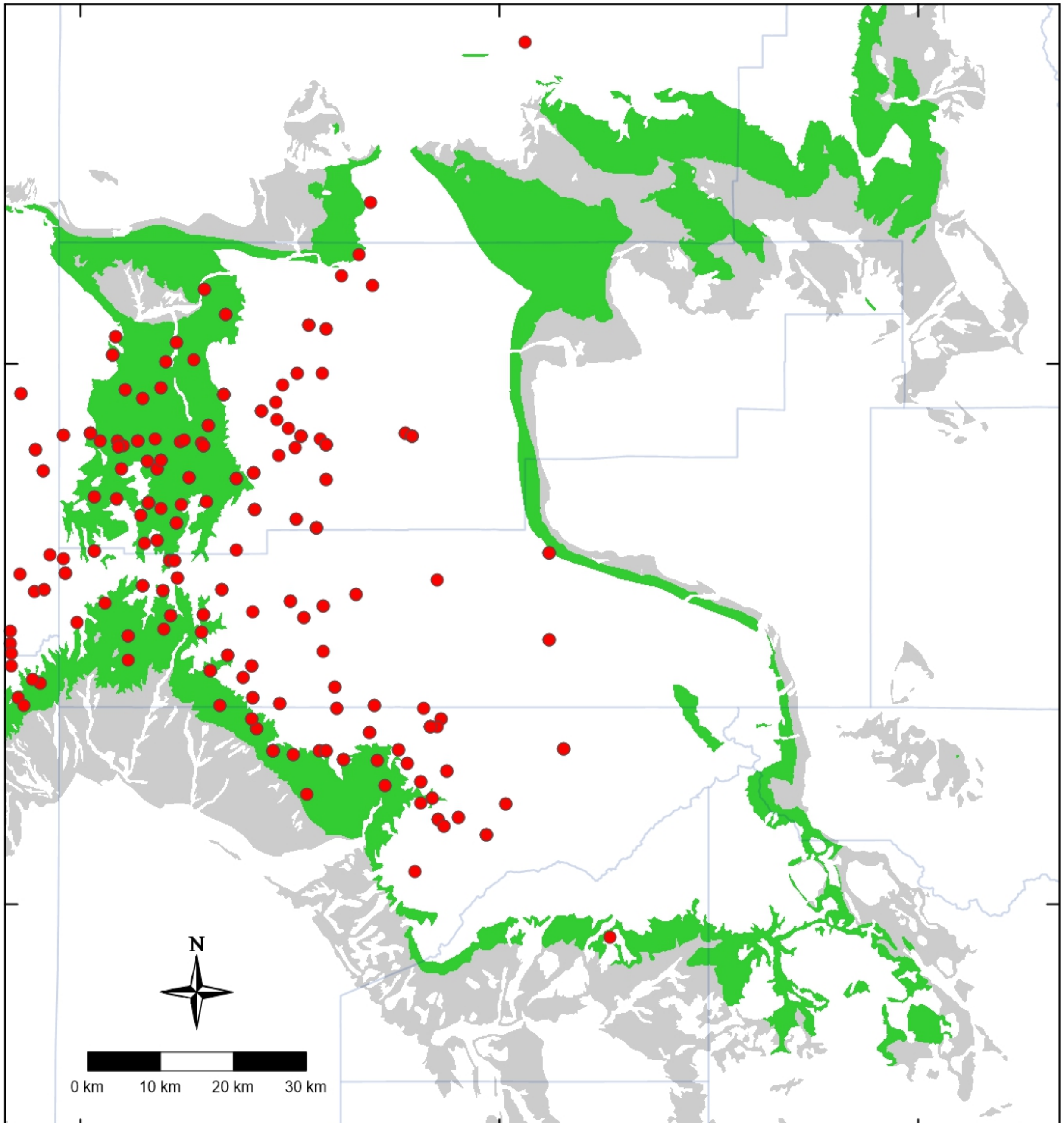
Ammonite Localities

- *Baculites asperiformis* fossil localities
- Data from USGS Denver Palentology Collection



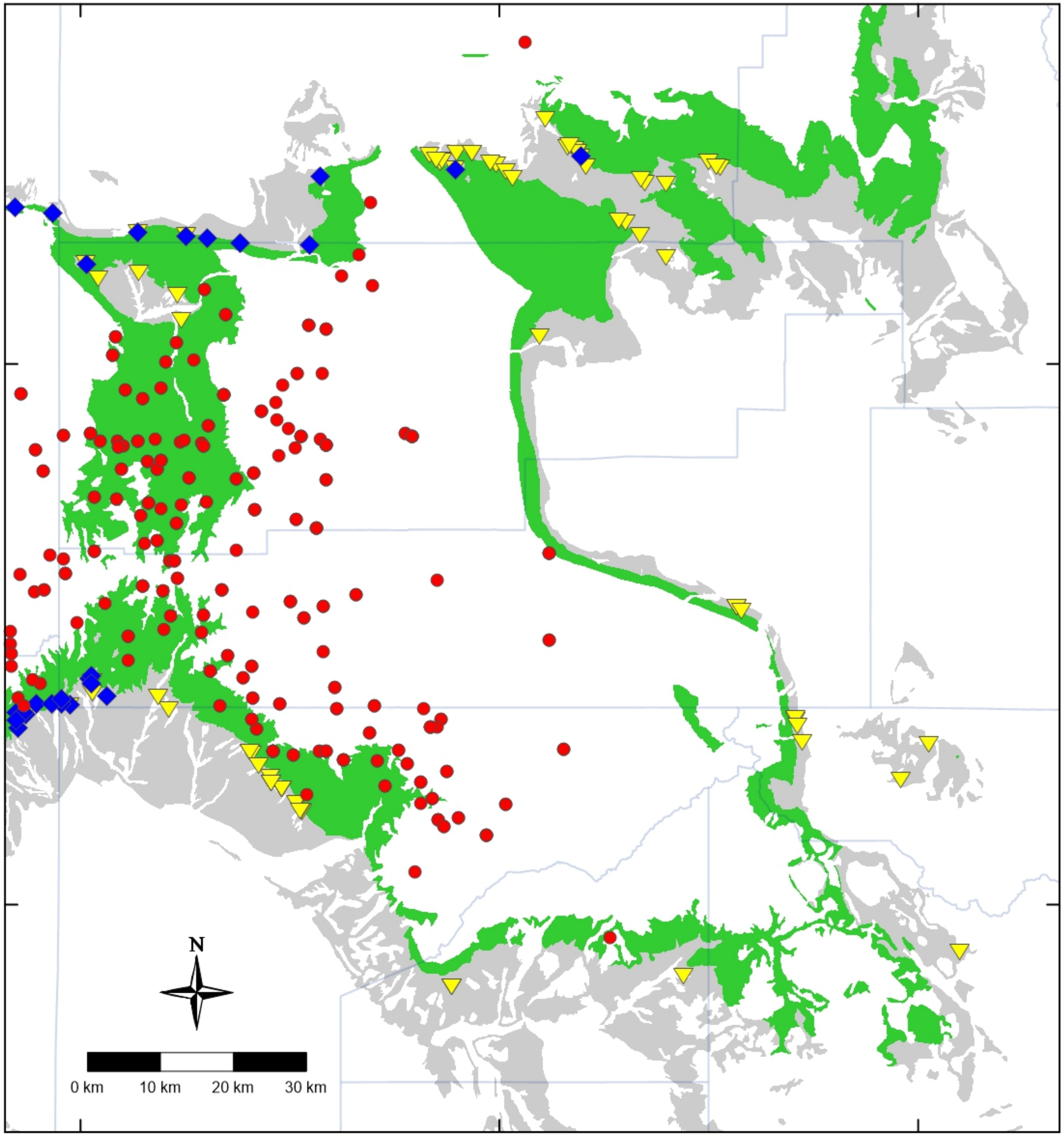
Stratigraphic Sections

- Young (1955)
- Gill & Hail (1975)
- Francyzk (1989)
- Van Wagoner et al. (1990)
- Van Wagoner (1991)
- Van Wagoner (1995)



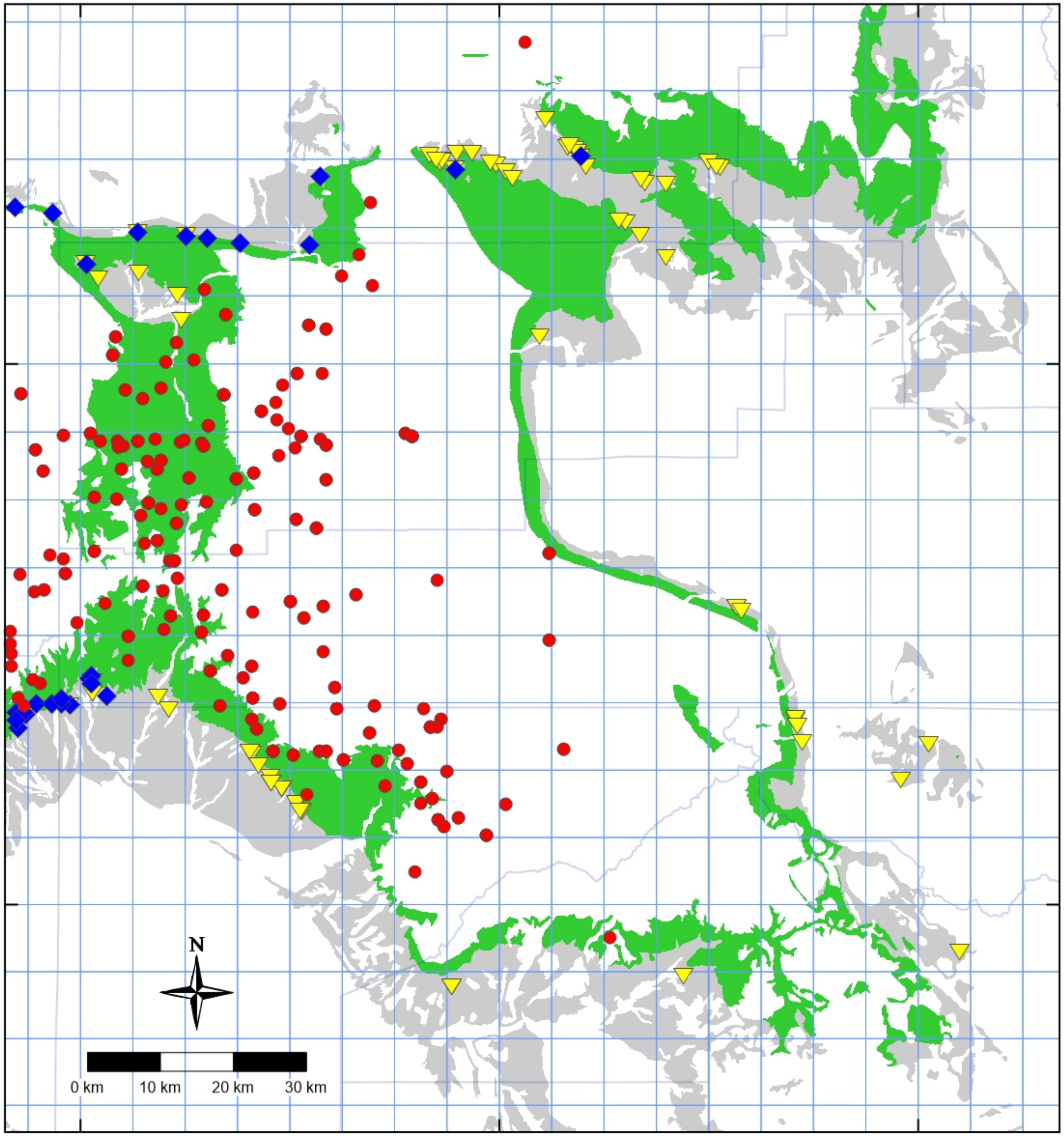
Subsurface Correlations

- Finley et al. (1983)
- Johnson (1986)
- Johnson (1987)
- Francyzk (1989)
- Johnson (1989)
- Cole et al. (1997)
- Hettinger & Kirschbaum (2002, 2003)
- Dubiel (2003)
- Johnson (2003a)
- Johnson (2003b)
- Patterson et al. (2003)
- Hampson (2010)
- Schwendeman (2011)
- Rogers (2012)
- Anna (2012)



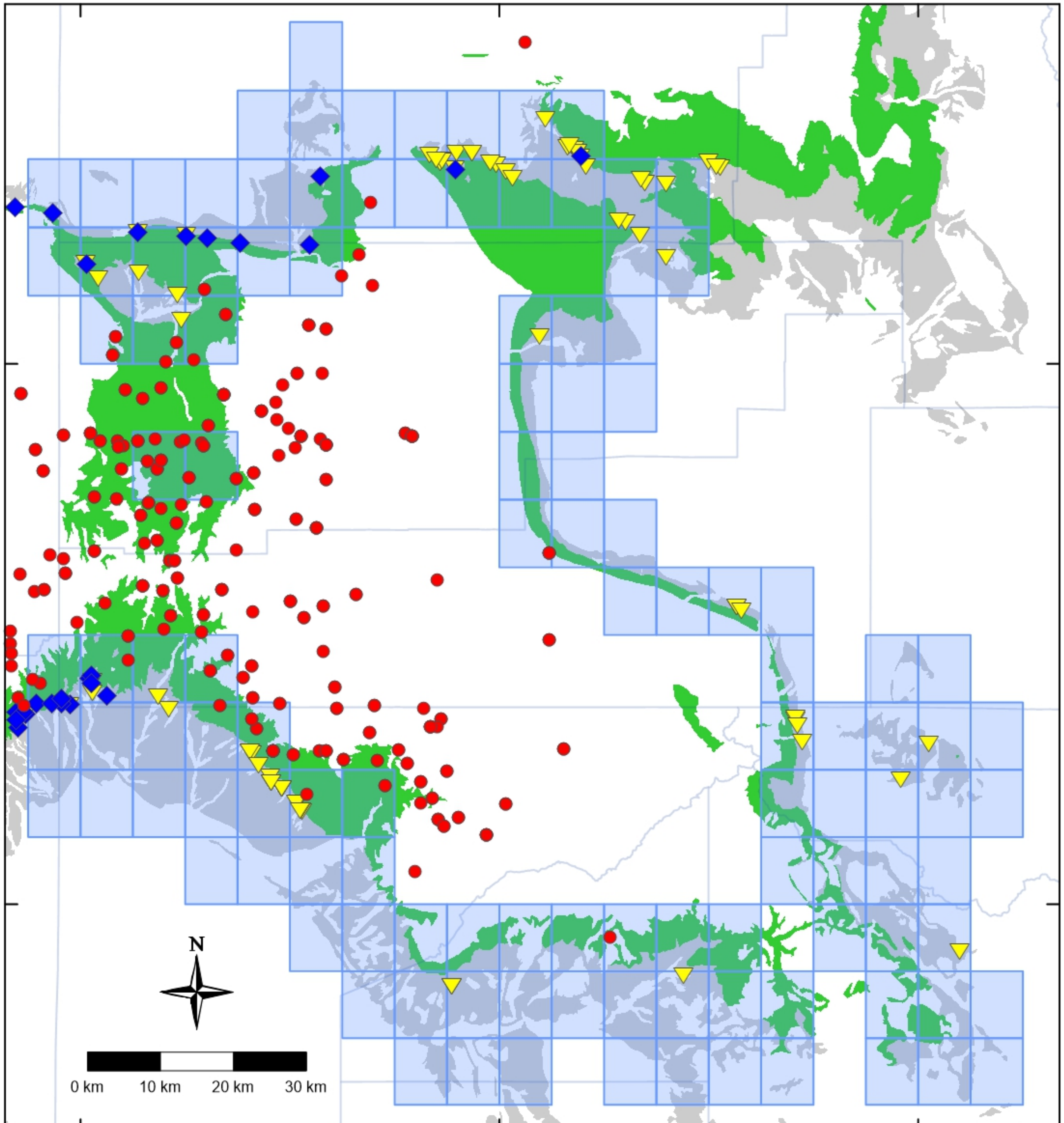
Initial Area-of-Interest

- Outlines areal extent of previously published data



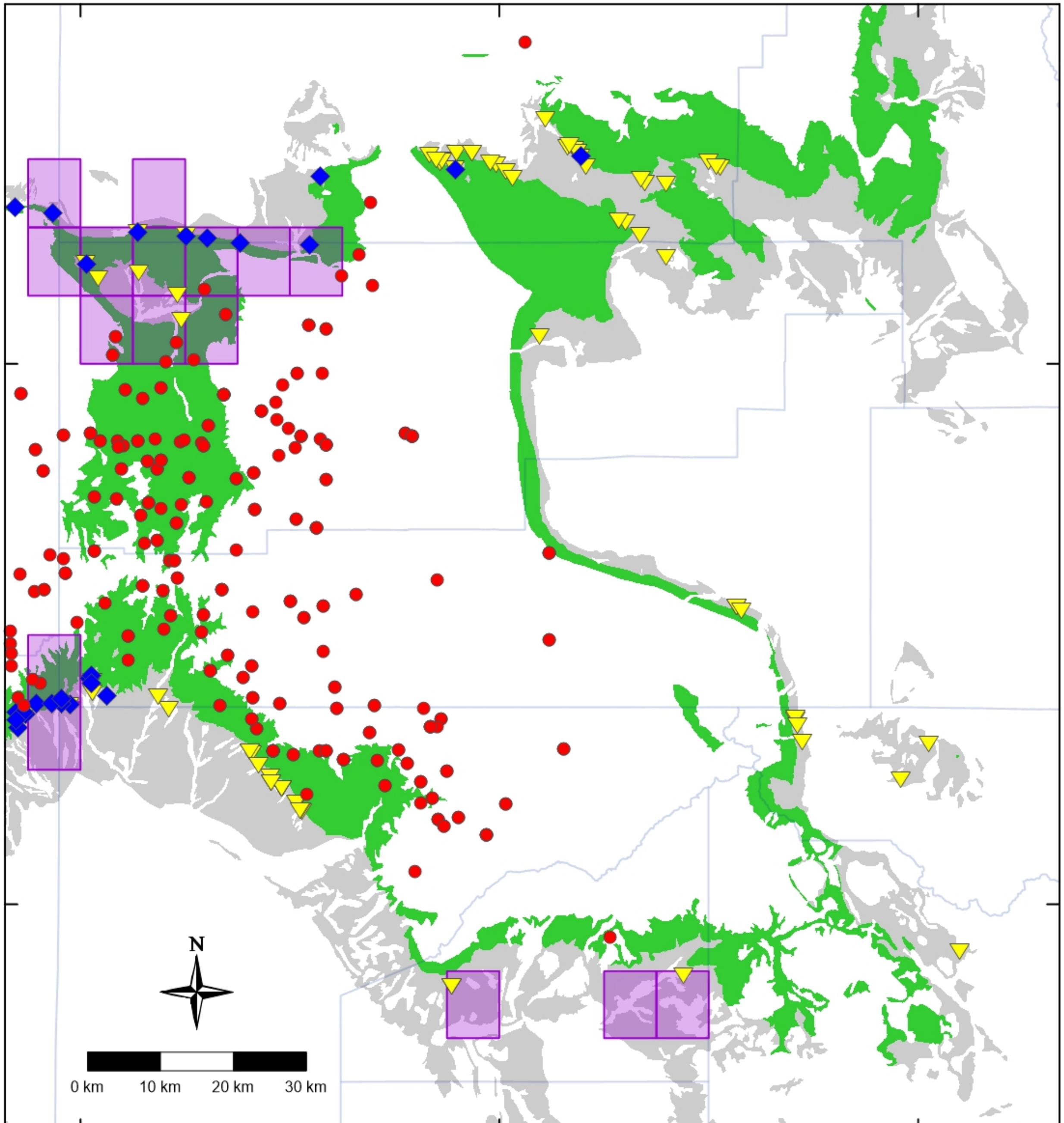
USGS Quadrangles

- Subdivide area by USGS quadrangles



USGS Quadrangles

- Index all quadrangles with age-equivalent geologic units
- Final dataset:
  - 165 quadrangles
  - 98 publications
  - 1,067 geologic units



USGS Quadrangles

- Quadrangles with Castlegate Sandstone explicitly described

Workflow

1. Data compilation
2. **Duplication of published well log correlations**
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4. Standardization of interpretations
5. Areal infilling
6. Areal expansion

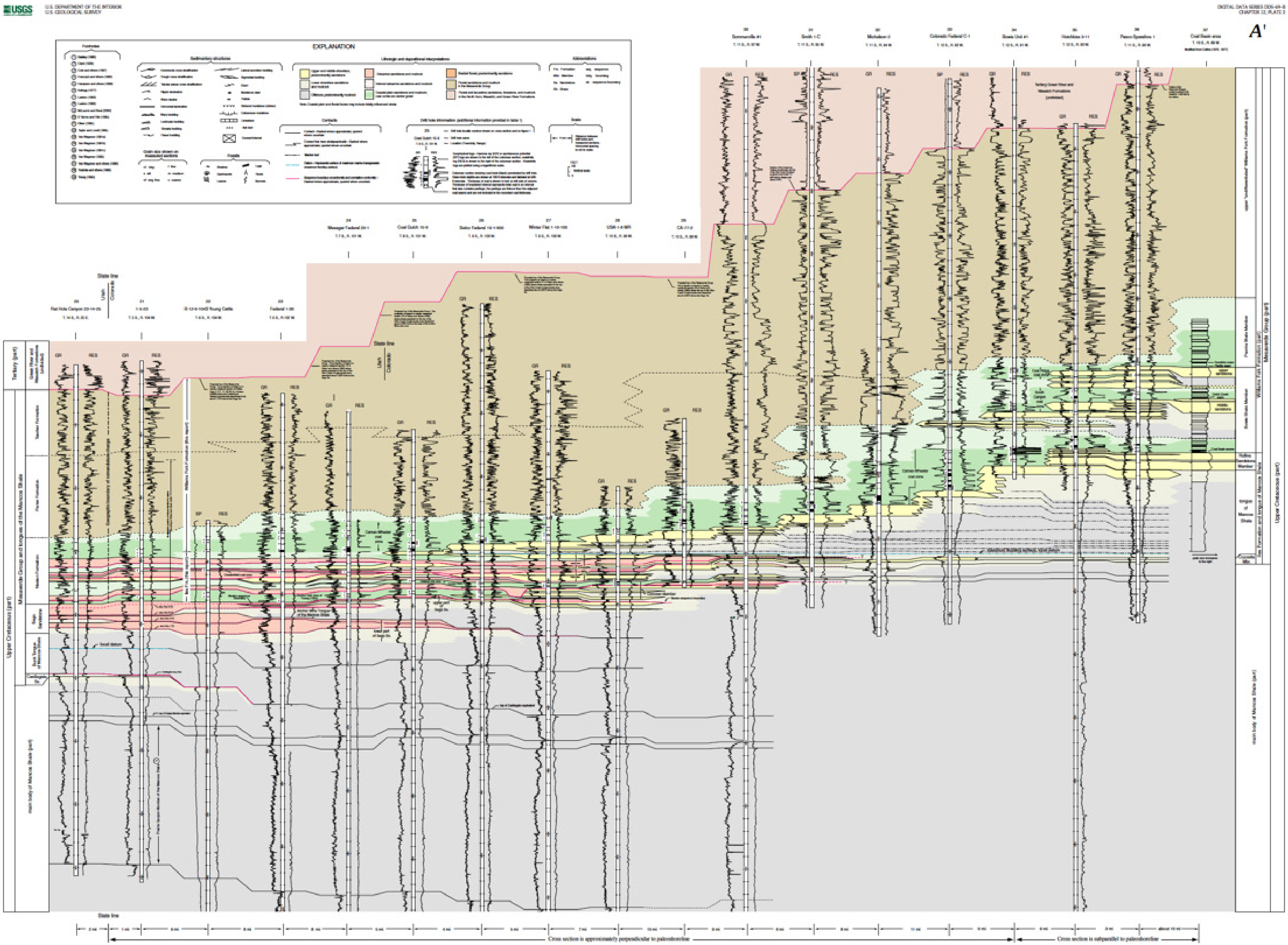
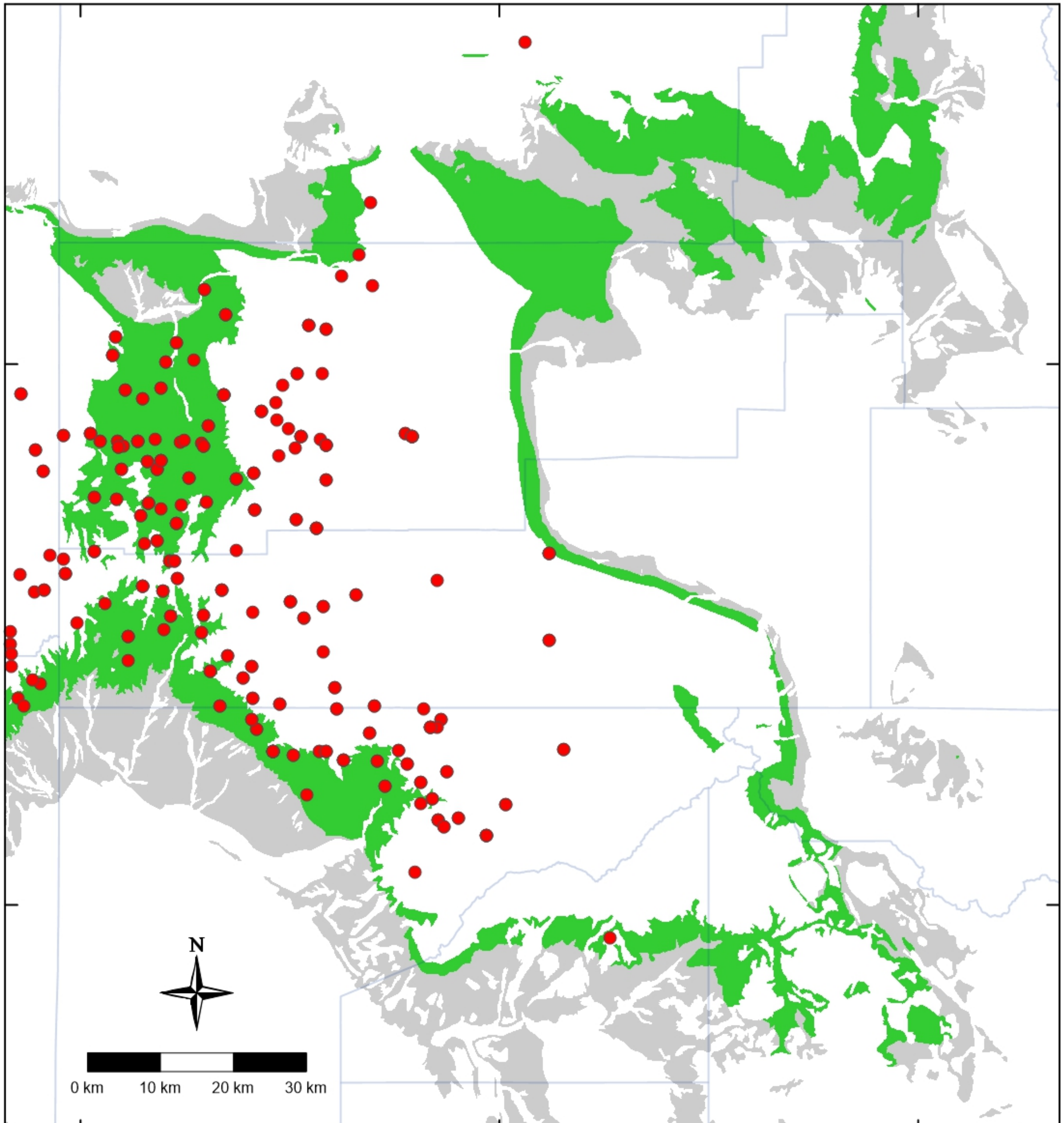


Figure from Hettinger & Kirschbaum (2003)



Replicating Correlations

- Assume all correlations are correct at first
- Pick tops for all wells before adding new data

Workflow

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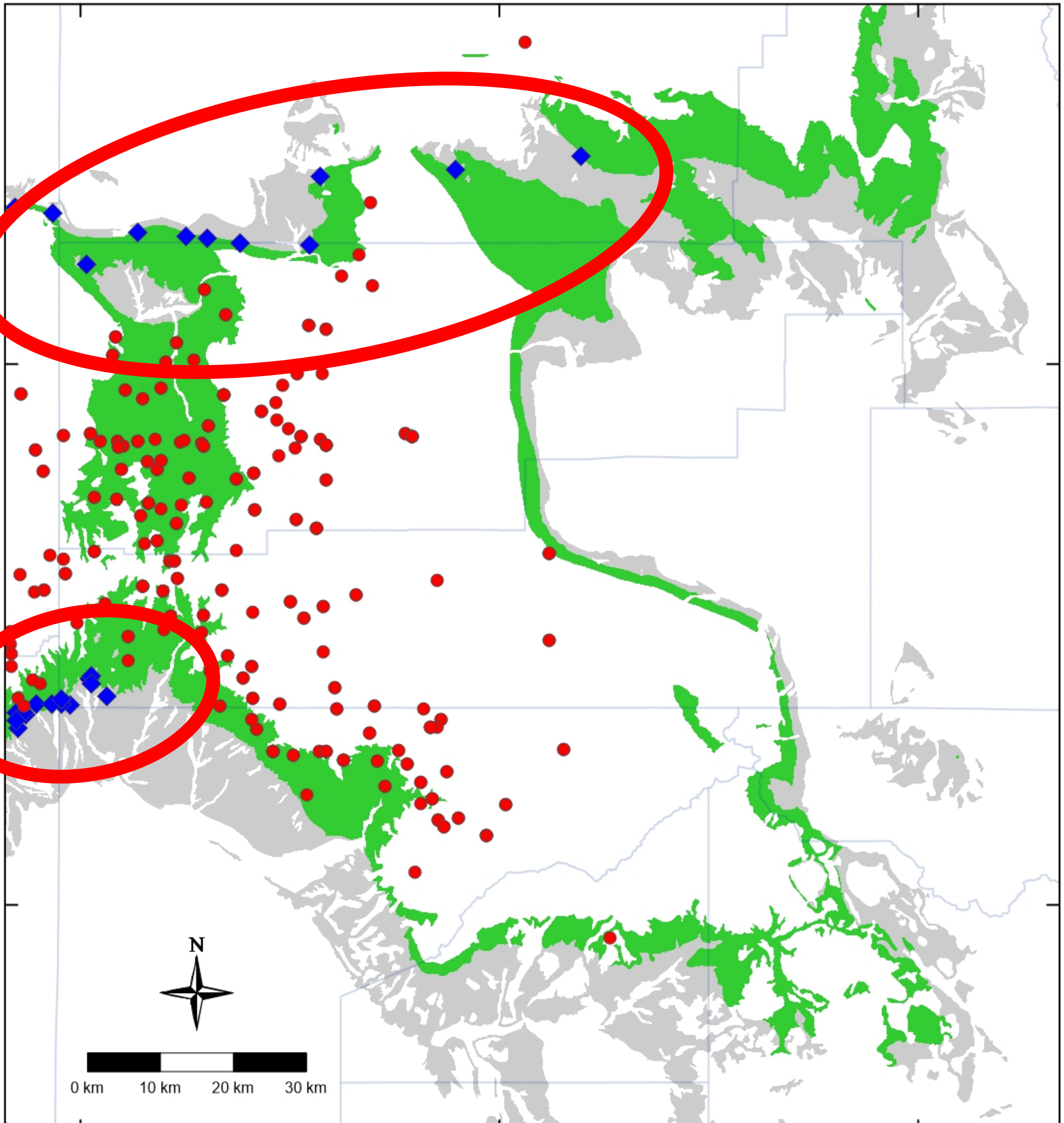
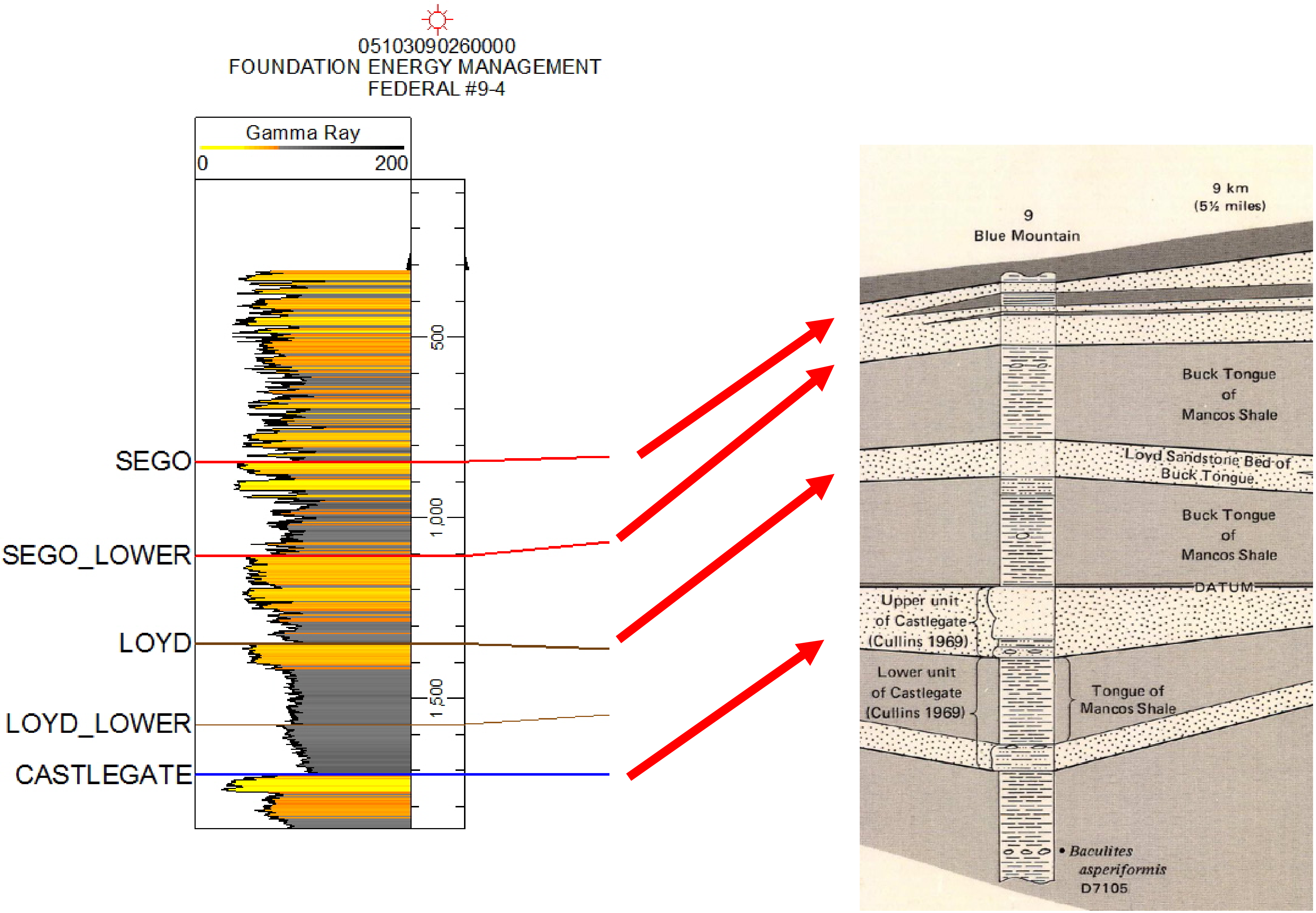


Outcrop-to-Subsurface Integration

- Compare-and-contrast well logs to nearby strat sections and geologic maps whenever possible



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FOUNDATION ENERGY MANAGEMENT
FEDERAL #9-4
Gamma Ray
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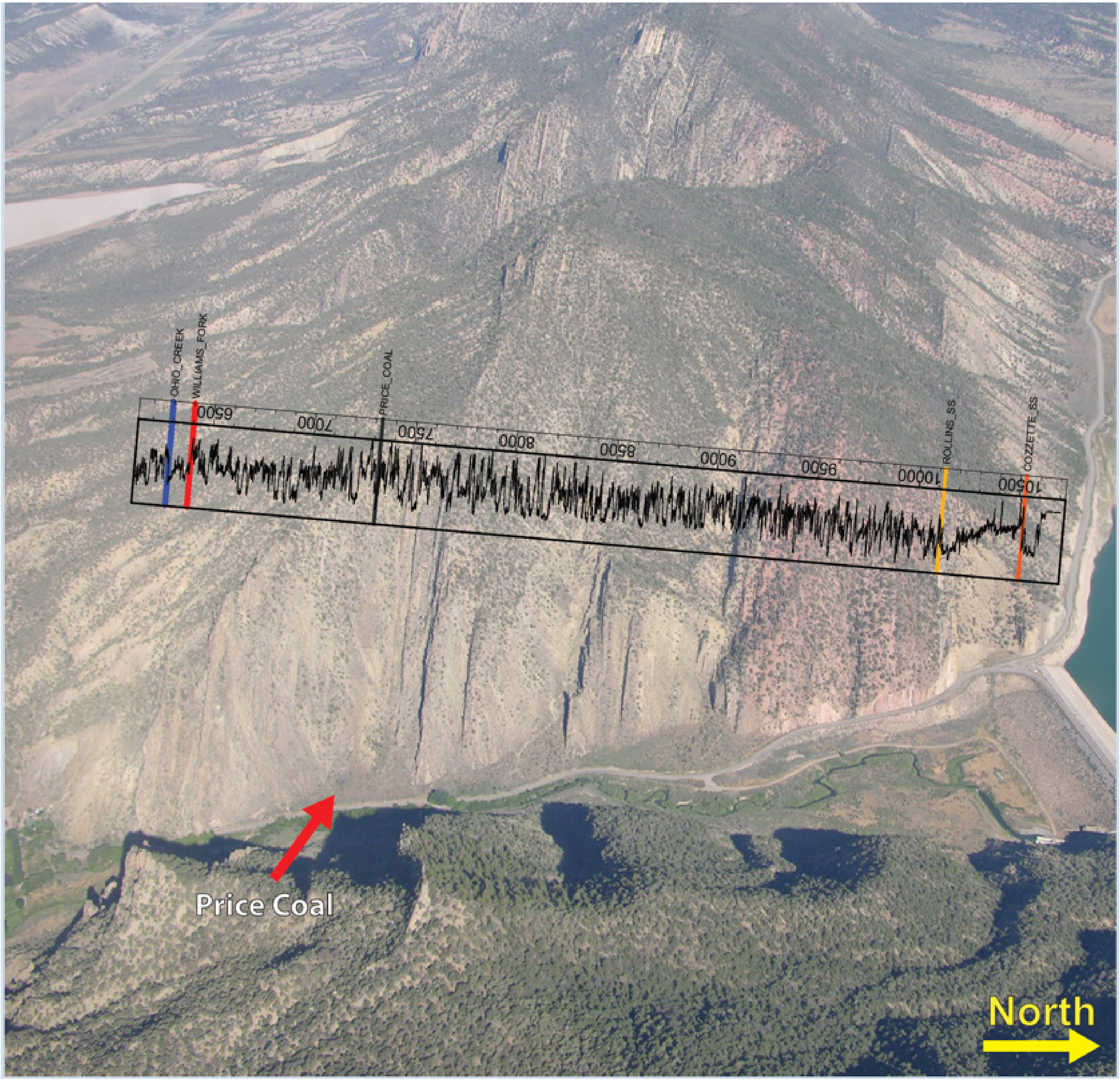
SEGO
SEGO_LOWER
LOYD
LOYD_LOWER
CASTLEGATE
9
Blue Mountain
9 km
(5½ miles)
Buck Tongue
of
Mancos Shale
Loyd Sandstone Bed of
Buck Tongue
Buck Tongue
of
Mancos Shale
DATUM
Upper unit
of Castlegate
(Cullins 1969)
Lower unit
of Castlegate
(Cullins 1969)
Tongue of
Mancos Shale
• Baculites
asperiformis
D7105



* Photo from Steve Cumella

Workflow

1. Data compilation
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4. **Standardization of interpretations**
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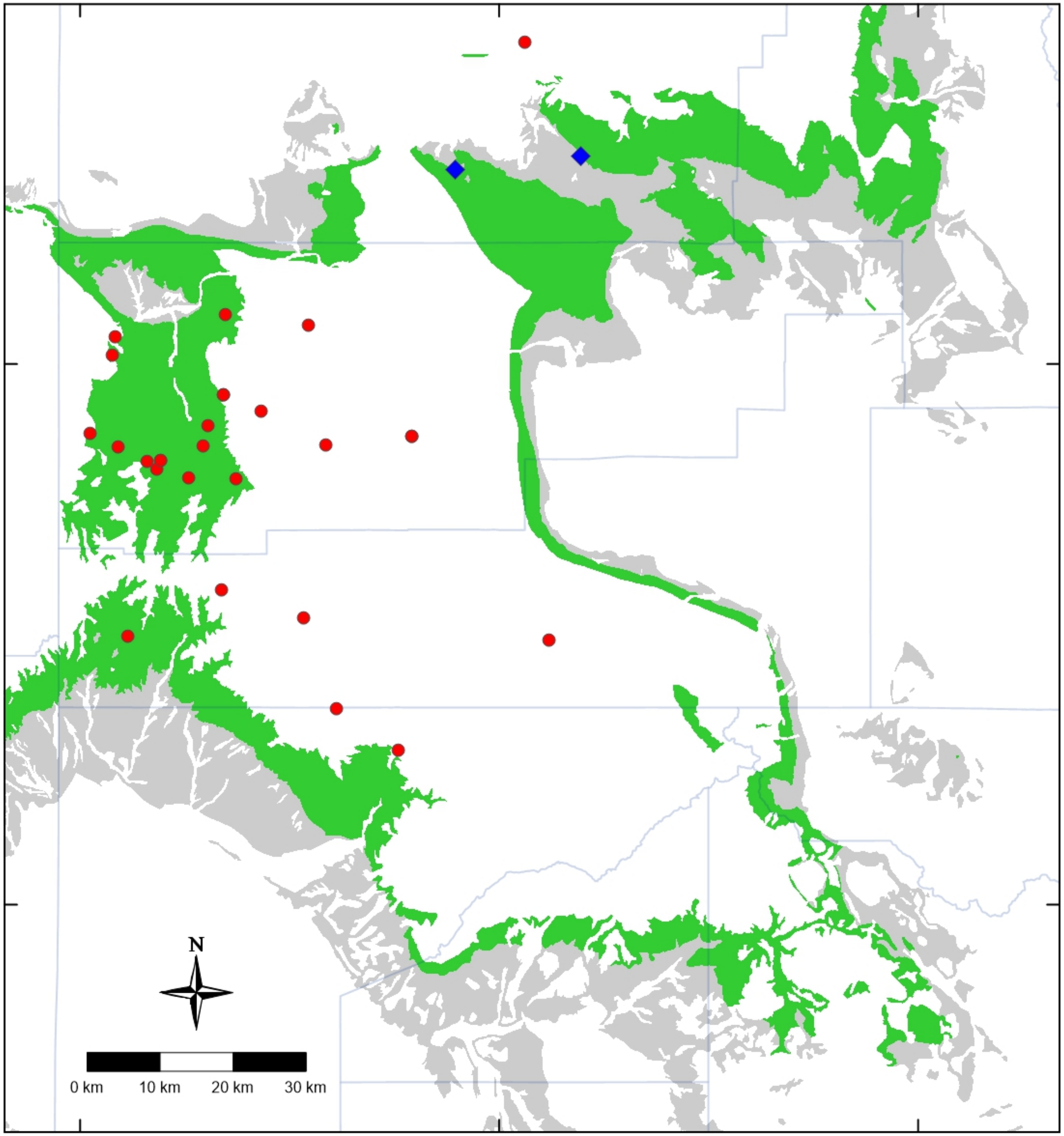
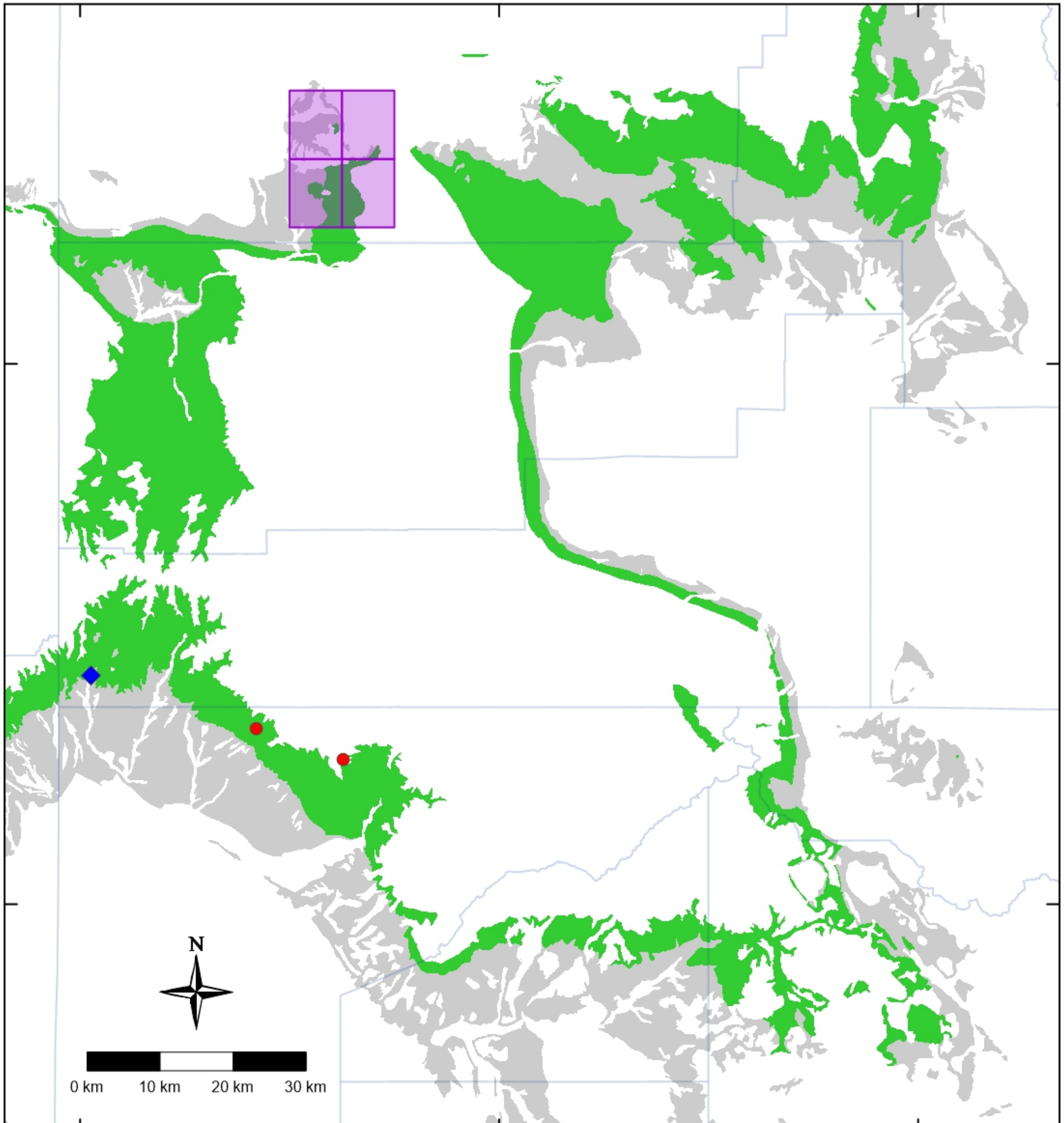
Standardization

- Split previously published data into 3 categories:
  - *True positives*
  - *False positives*
  - *False negatives*



False Positive Data

- Strat sections
  - Gill & Hail (1975)
- Subsurface correlations
  - Finley et al. (1983)
  - Johnson (2003b)
  - Patterson et al. (2003)
  - Anna (2002)

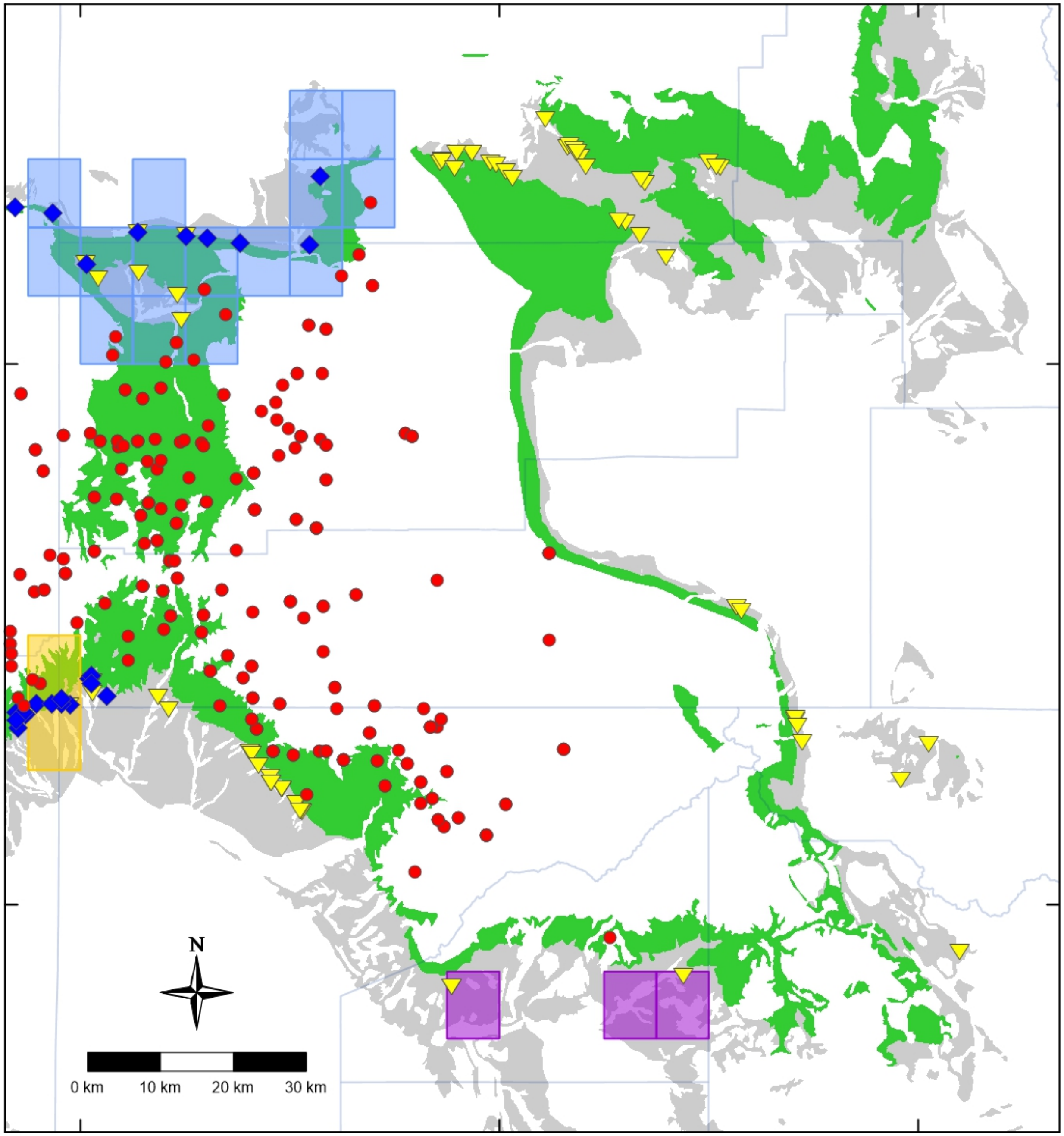


False Negative Data

Strat sections
- Fischer (1960)

Subsurface correlations
- Anna (2012)

Geologic maps
- Dyni (1968)

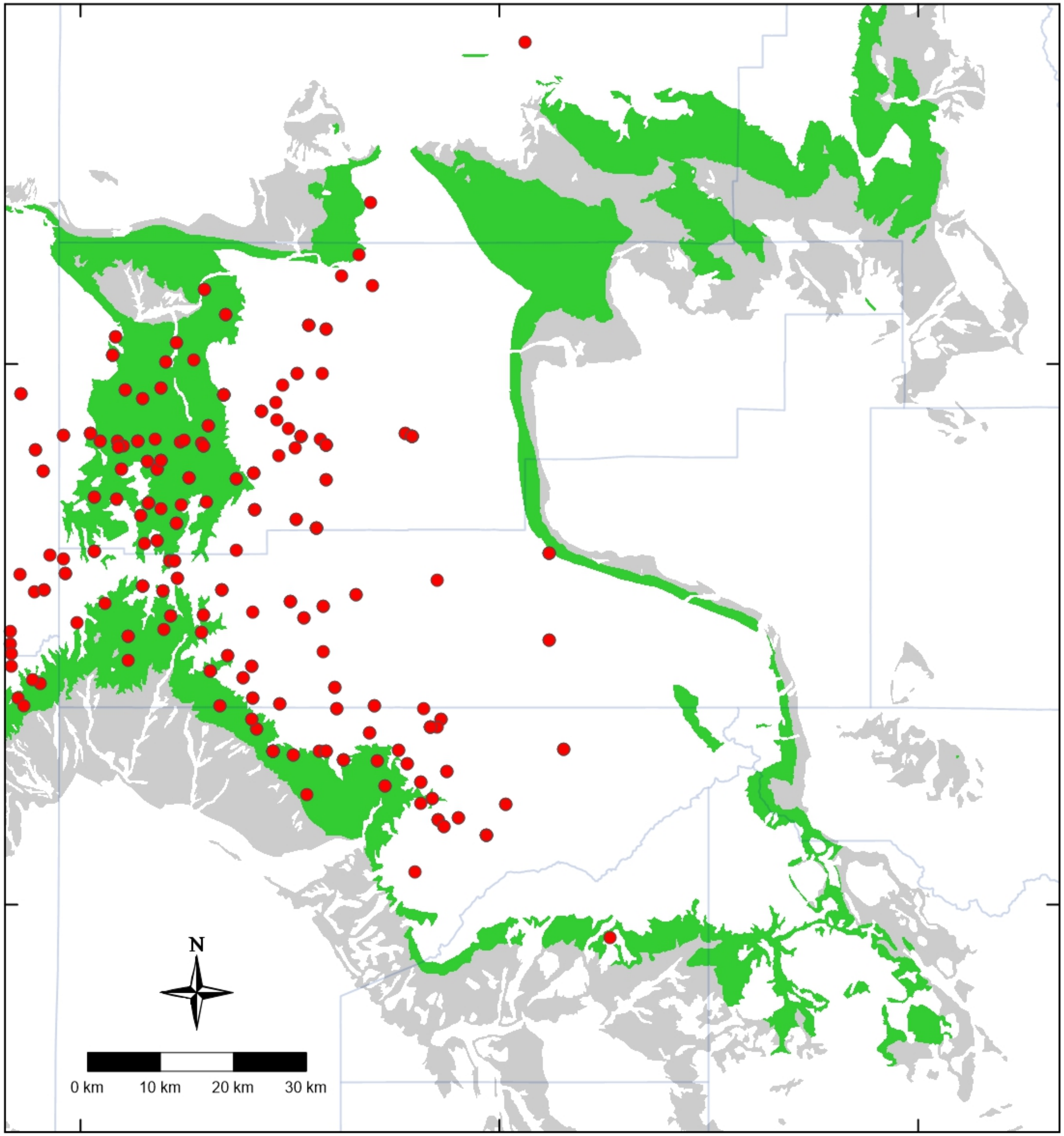


Final Dataset

- After standardization

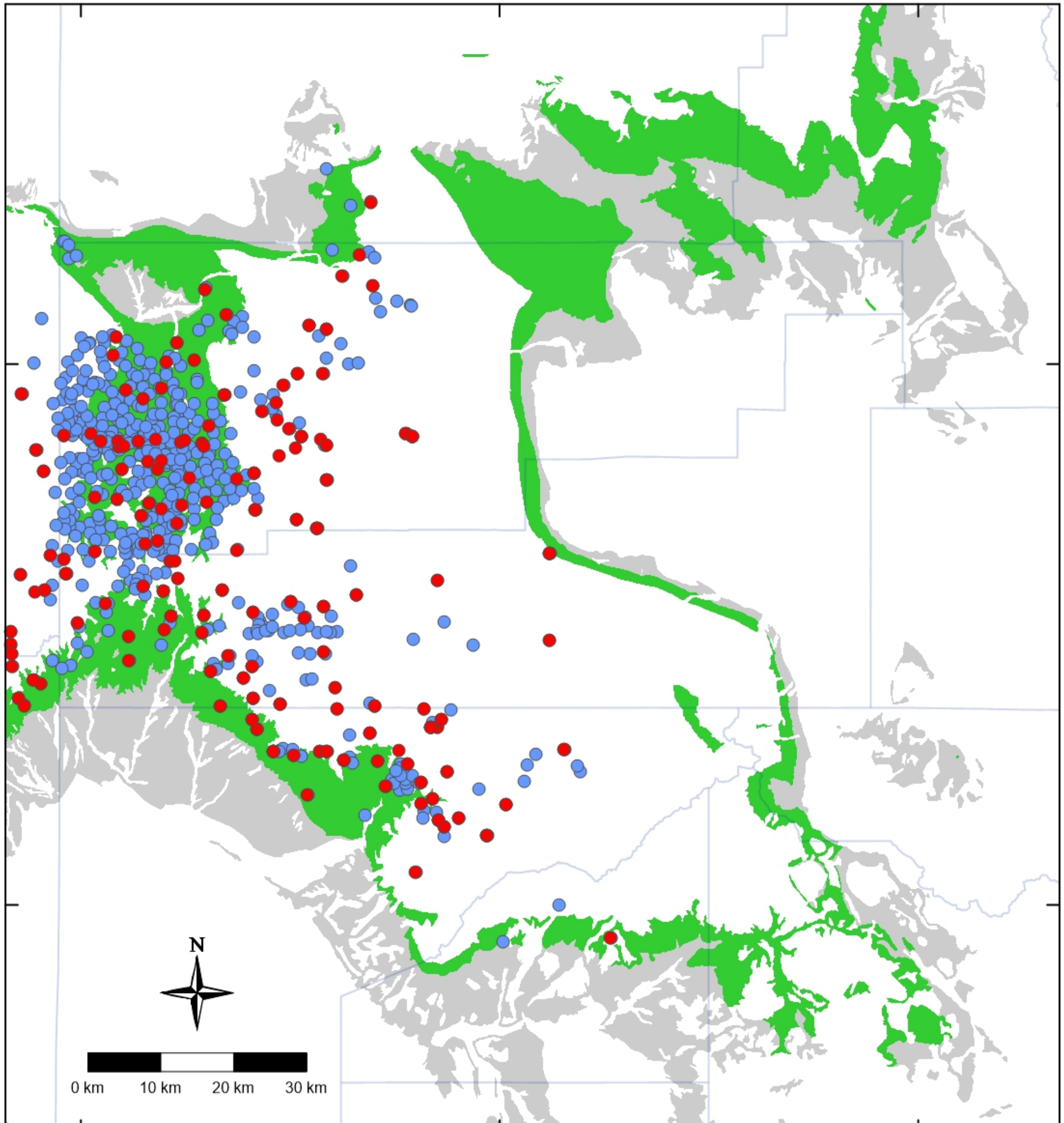
Workflow

1. Data compilation
2. Duplication of published well log correlations
3. Subsurface-to-outcrop data integration
4. Standardization of interpretations
5. **Areal infilling**
6. Areal expansion



Areal Infilling

- Initial well count (e.g., seed wells)



Areal Infilling

- Based on well log availability

Workflow

1. Data compilation
2. Duplication of published well log correlations
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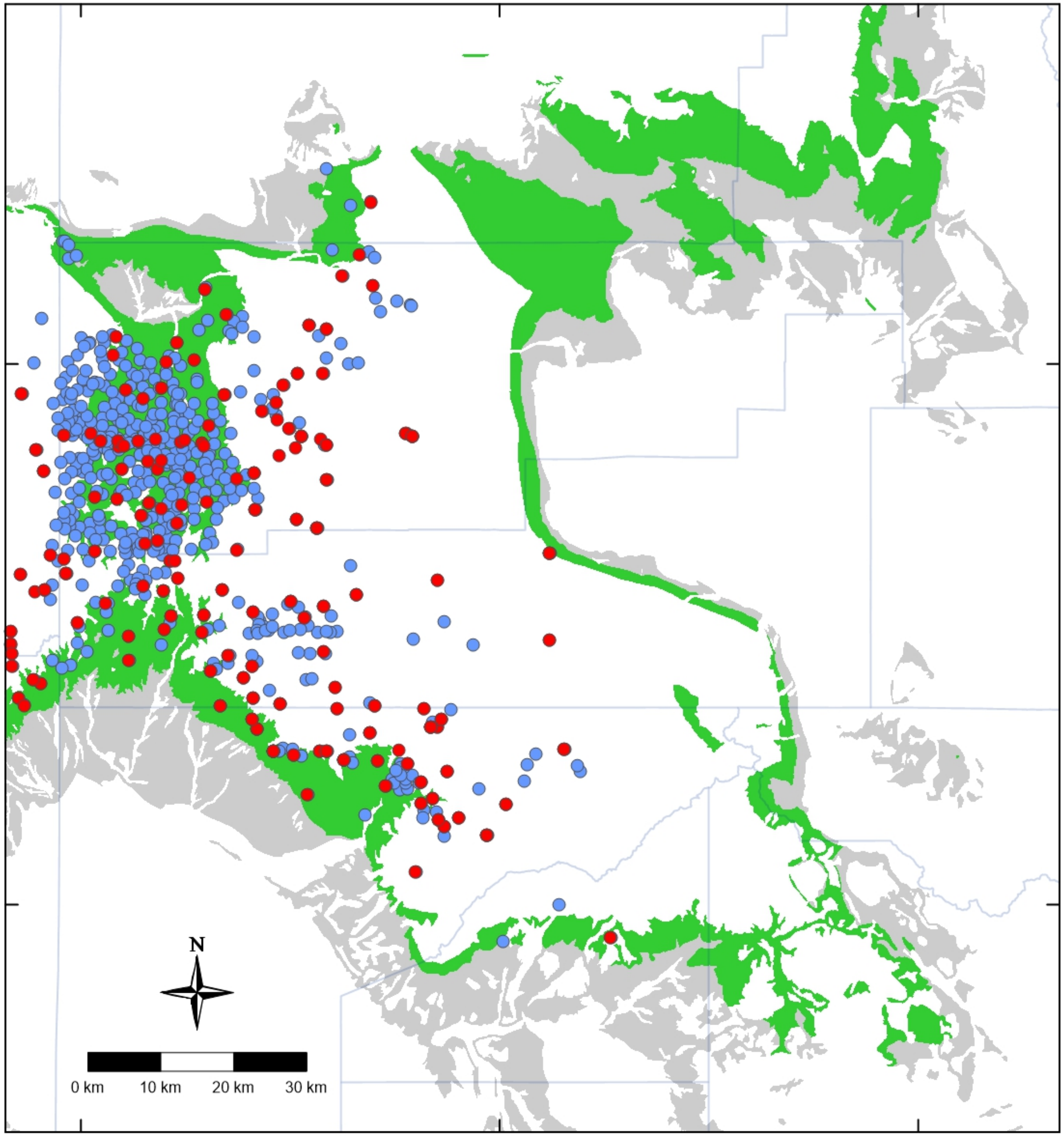
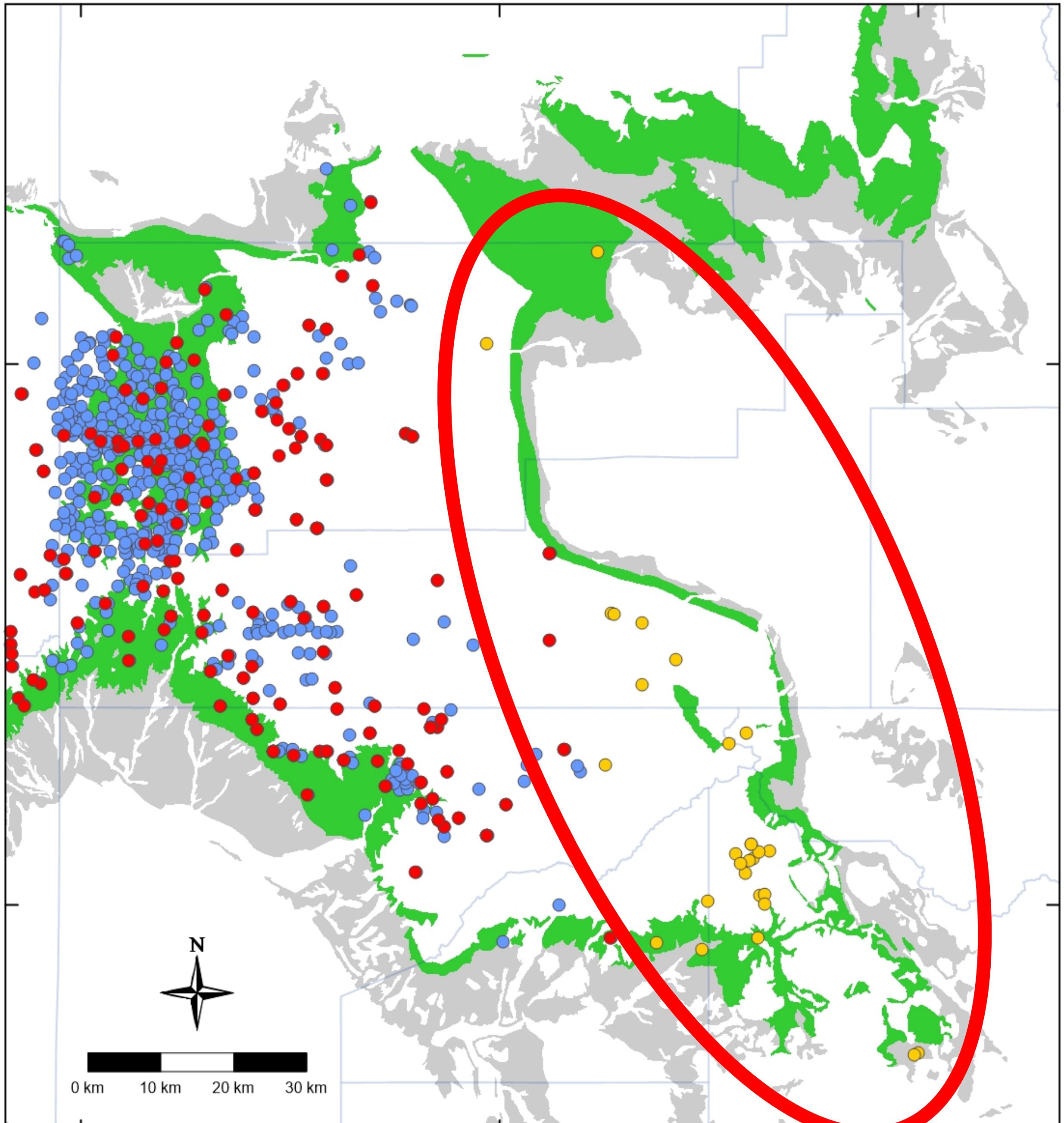
4. Standardization of interpretations
5. Areal infilling
6. **Areal expansion**



Areal Expansion

- Limited originally to initial area-of-interest (AOI)



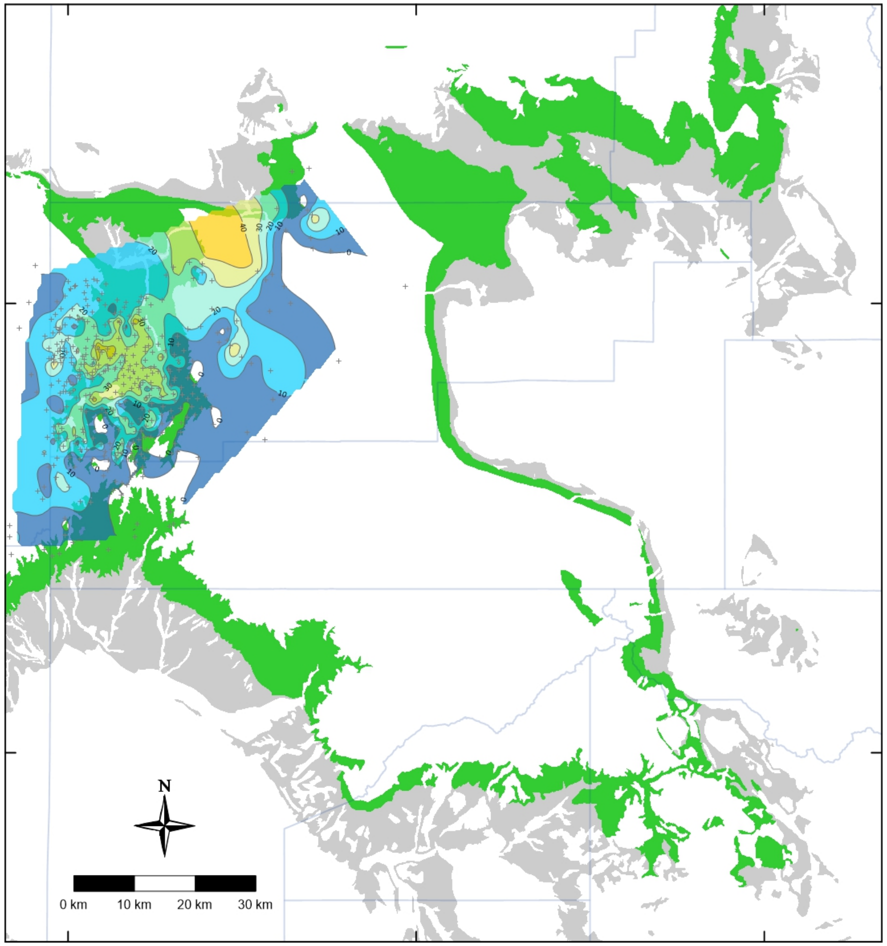
Areal Expansion

- Limited originally to initial area-of-interest (AOI)
- Expanded by well log availability and fossil control on basin margins

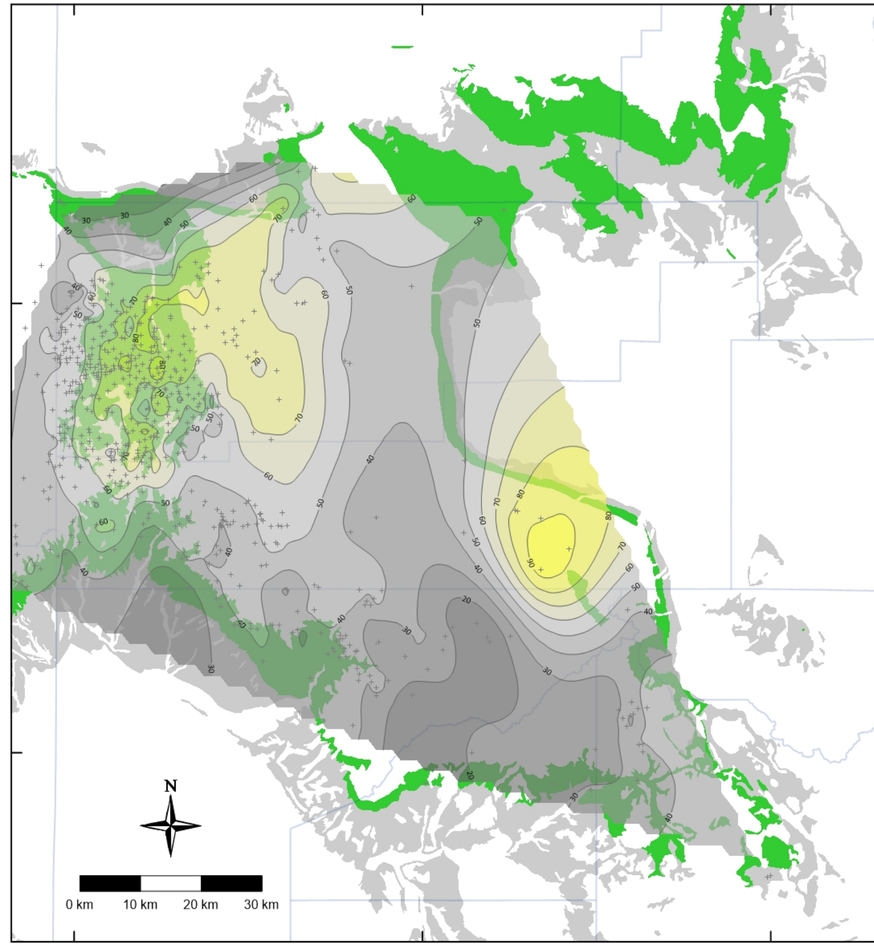
Why Do We Care?

- Allows us to build robust chronostratigraphic frameworks that help constrain subsurface correlations
- Currently applying this workflow to other Campanian- and Maastrichtian-aged sandstones in the Piceance basin:
  - Lion Canyon Sandstone
  - Upper Sandstone
  - Middle Sandstone
  - Rollins/Trout Creek Sandstone
  - Cozzette Sandstone
  - Corcoran Sandstone
  - Upper/Lower Sego Sandstone
  - Loyd Sandstone
  - Castlegate Sandstone
  - Desert/Morapos/B Sandstone

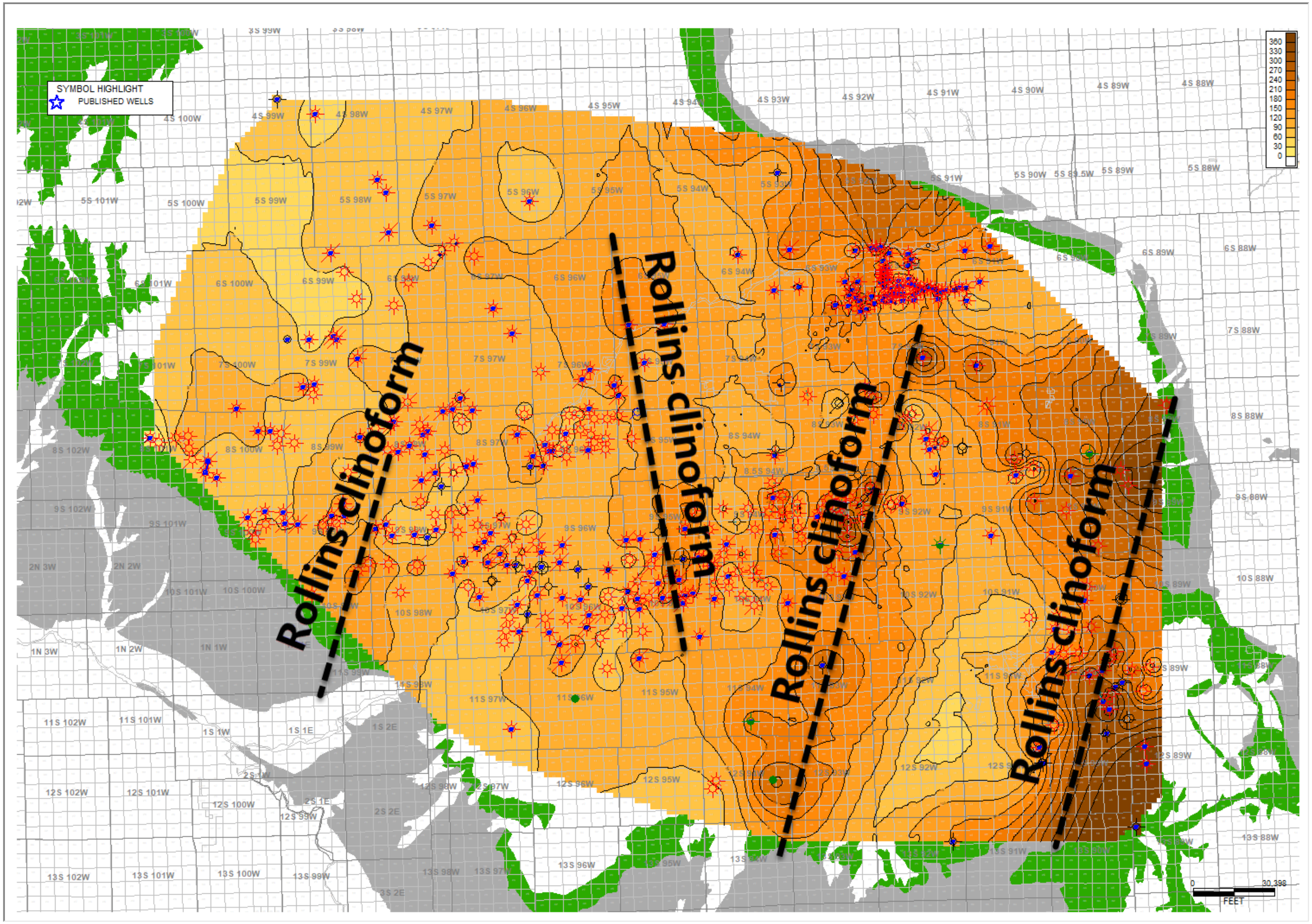
Gross Sandstone Thickness



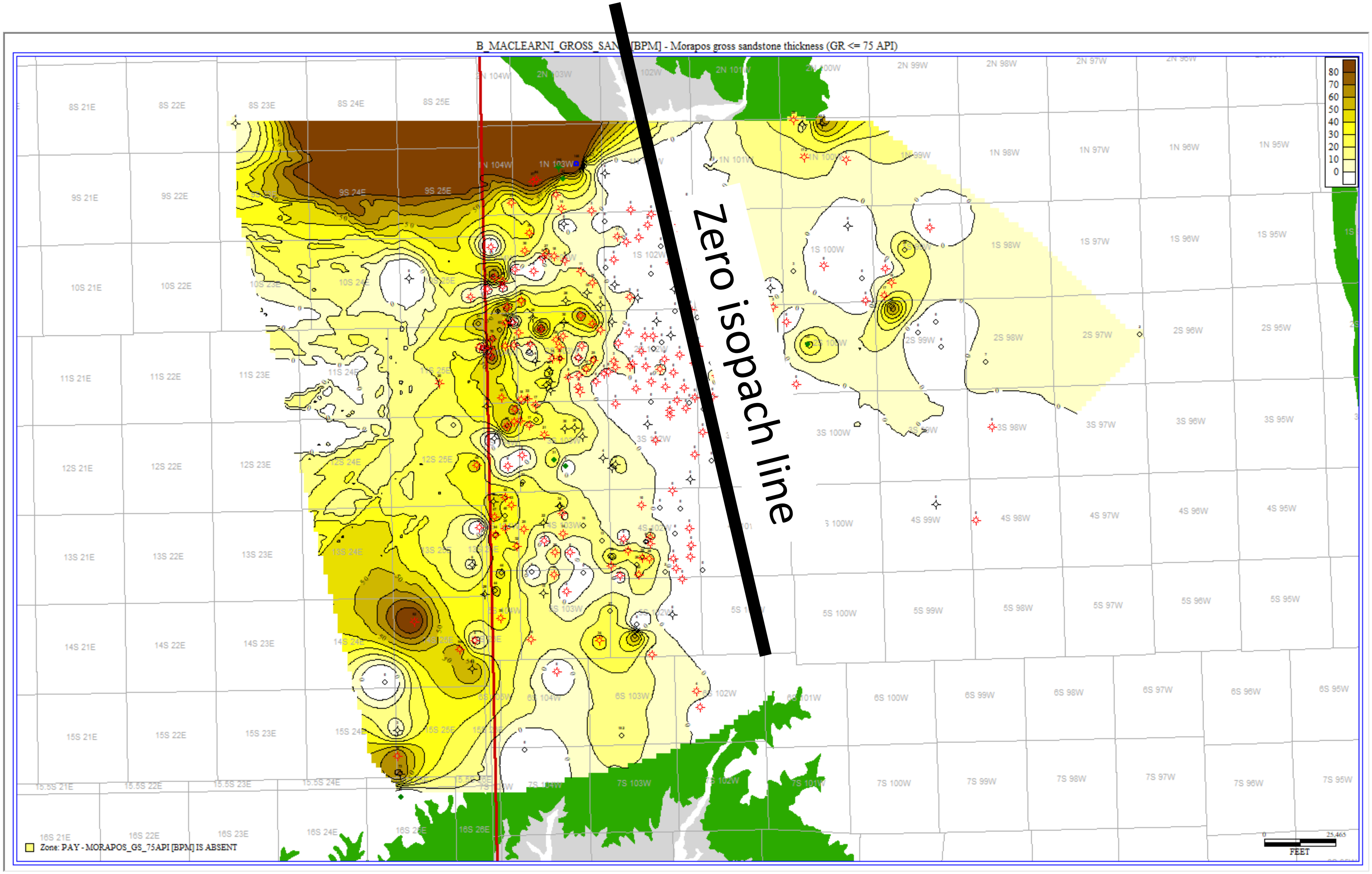
Gross Interval Thickness



*Castlegate Member, Mancos Group



*Rollins Sandstone Member, Iles Fm



*Desert Mbr, Blackhawk Fm; B Sandstone of Dyni (1968); Morapos Sandstone

Acknowledgements

- Casey McKinney (USGS Core Research Center)
- Mark Kirschbaum, Donna Anderson, Steve Cumella
- U.S. Department of Energy
    - Funding provided by RPSEA grant

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