Geomorphic Elements in Modern Continental Sedimetary Basins – Implications for Groundwater Basins in California

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Goals and Outline

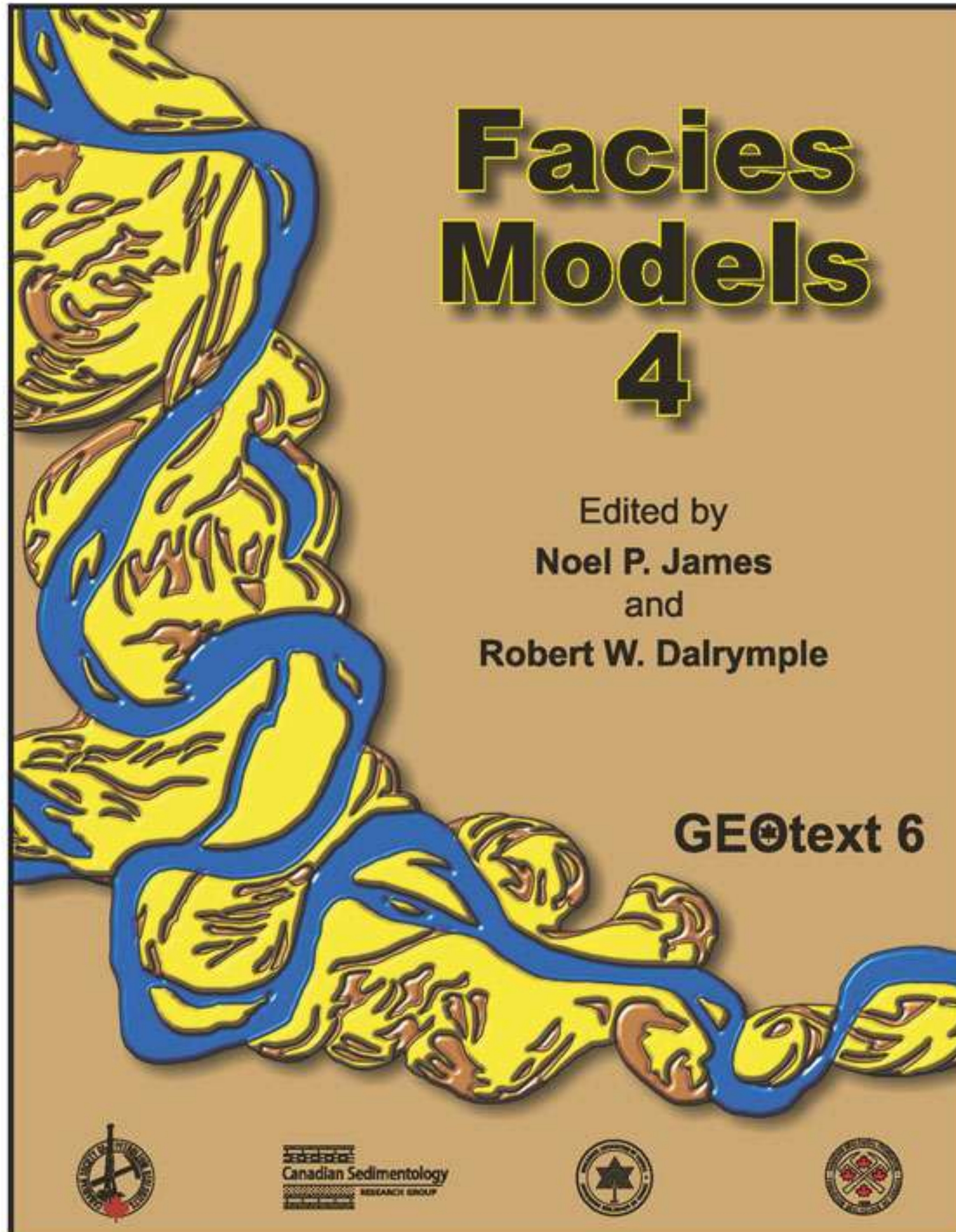
- General concepts on basin-scale controls on fluvial facies distributions – fluvial sedimentology using reasonable modern analogs
  - Evaluations of modern continental sedimentary basins
    - Distributive Fluvial Systems (alluvial fans, fluvial fans, and megafans)
    - Axial fluvial systems
  - Expected facies trends for fluvial systems

- Relationship to California hydrogeology and petroleum geology
  - San Joaquin Basin studies

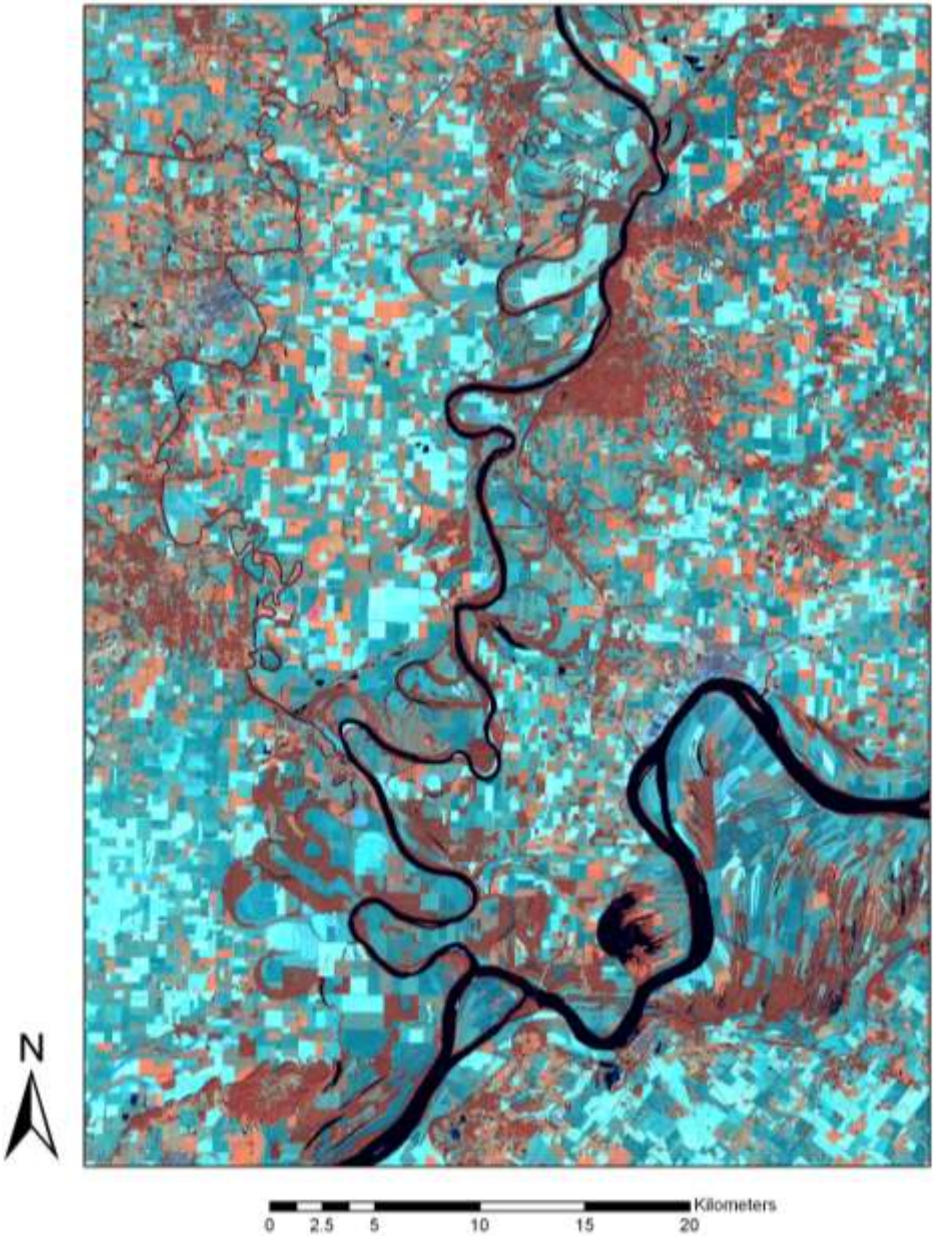
- What river deposits ultimately become sedimentary rocks?
- What is the geomorphology of these rivers?
- Why is this important for prediction of aquifer form?

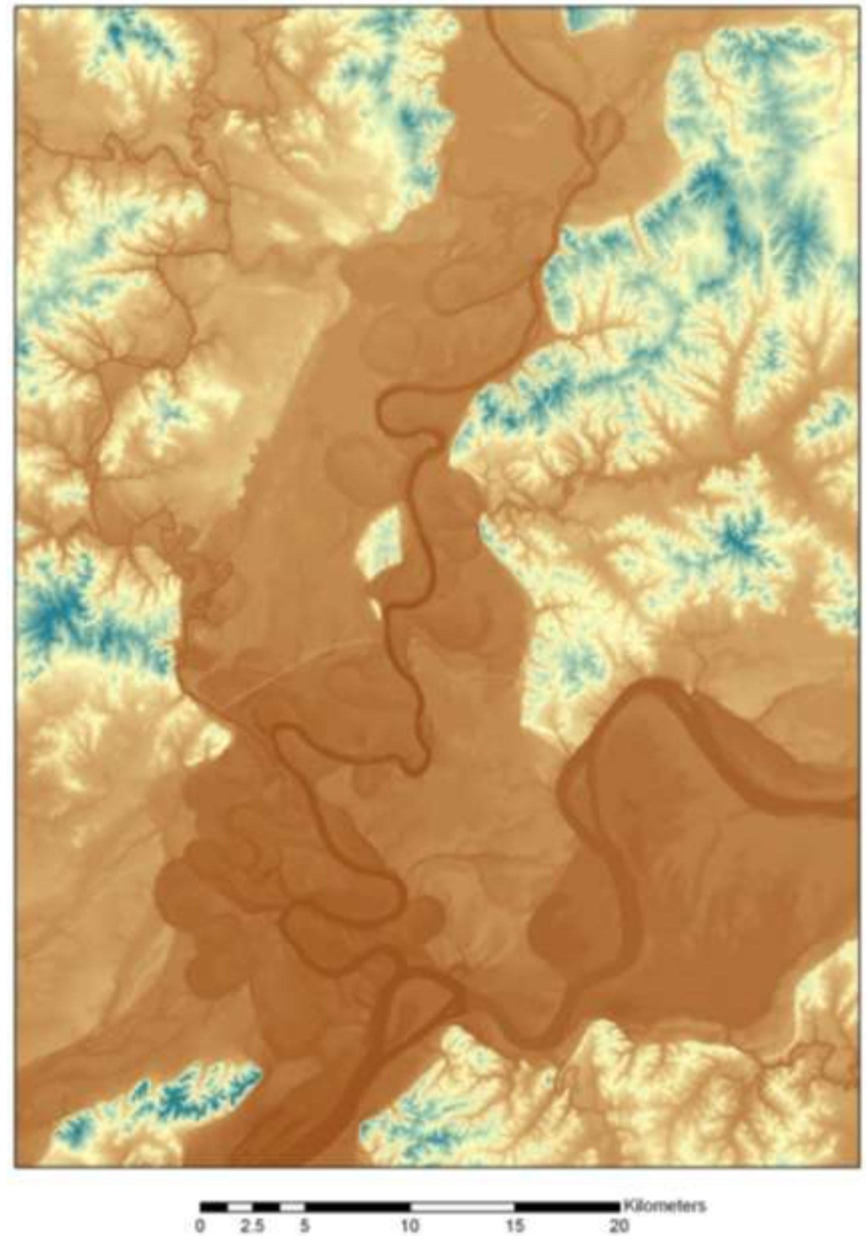
What modern river analogs make up our facies models??

Morrison Formation, New Mexico

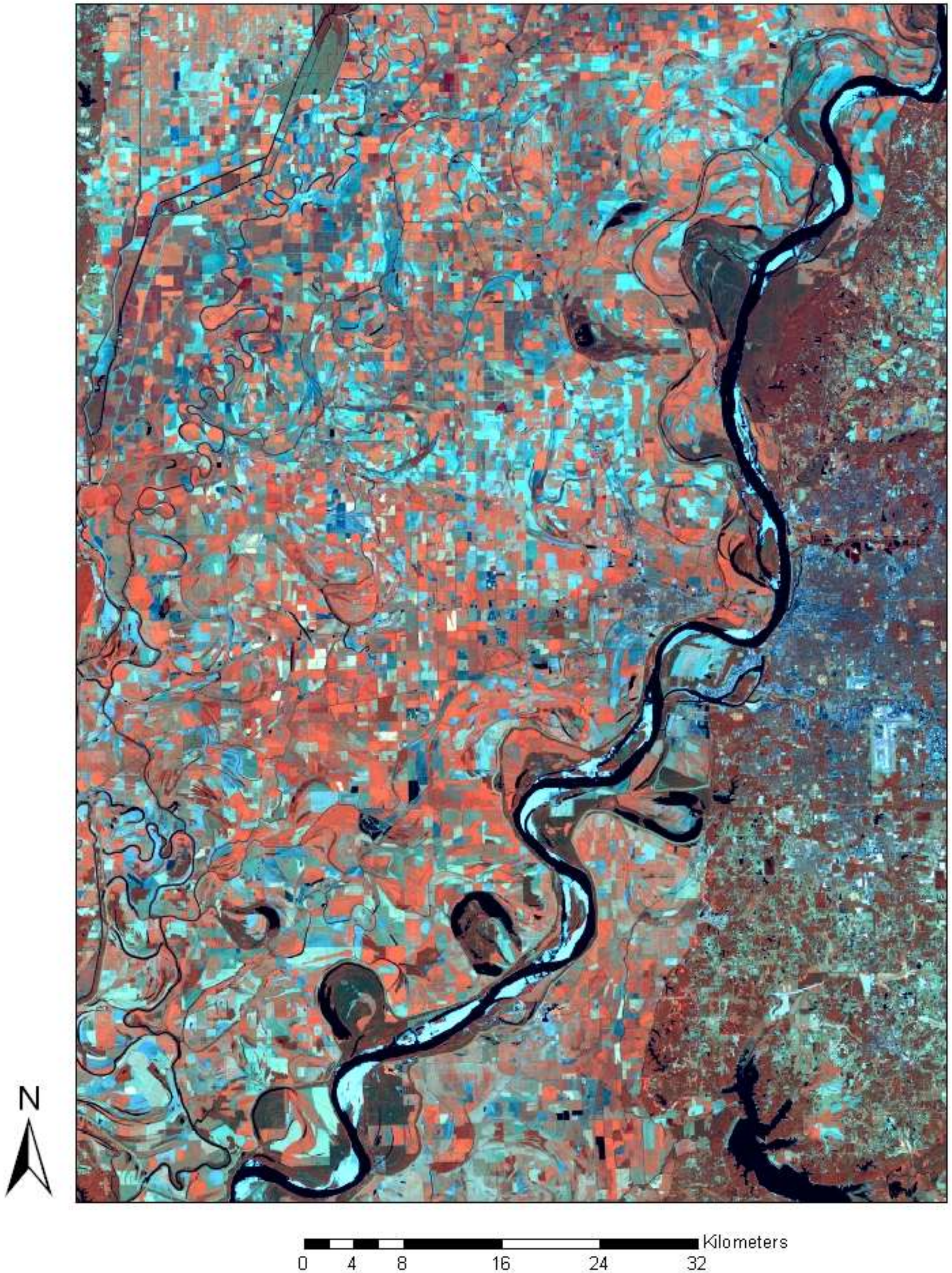


Wabash River, Illinois, USA (Jackson papers)



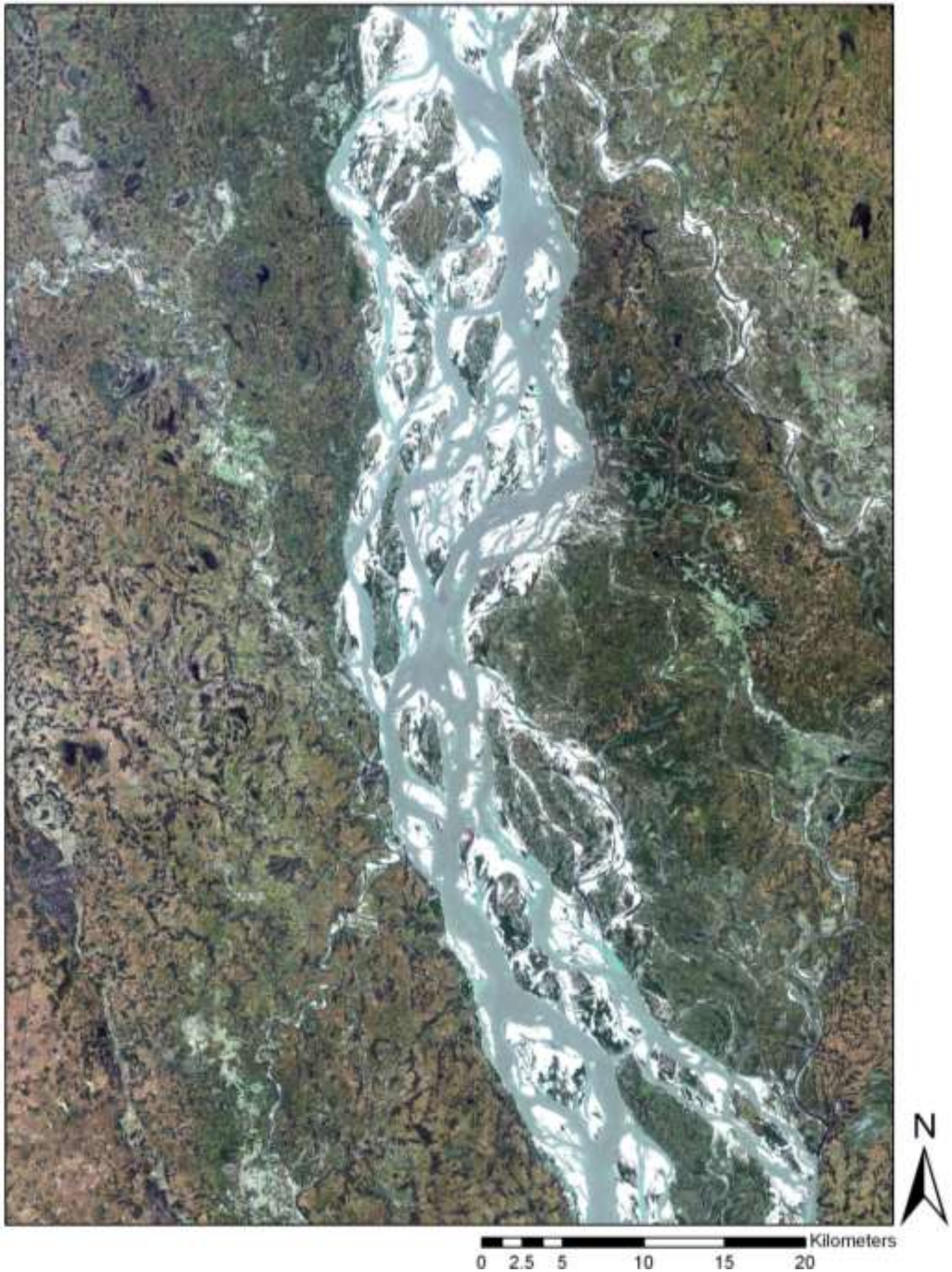


Upper Mississippi River, Arkansas, USA



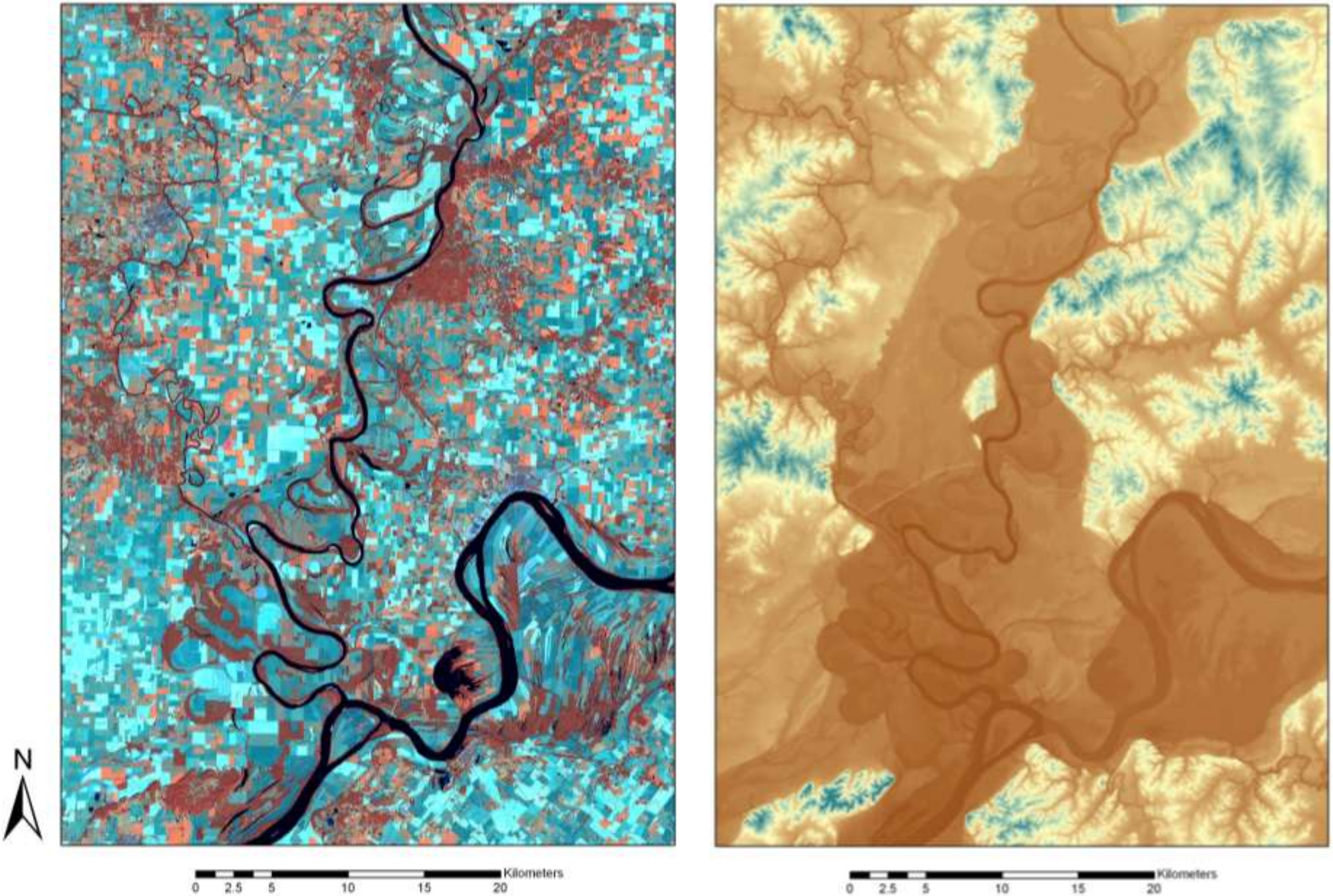
South Platte River – Colorado, USA

Lower Brahmaputra River, Bangladesh



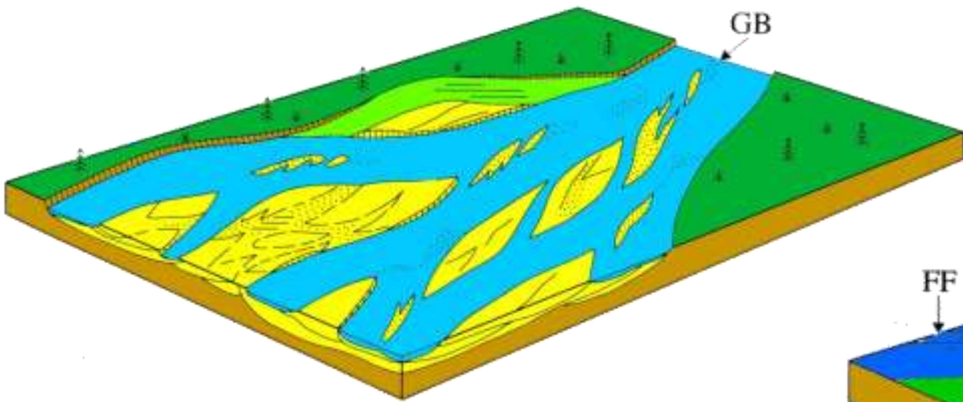
Kicking Horse River, British Columbia, Canada

Wabash River, Illinois, USA (Jackson papers)

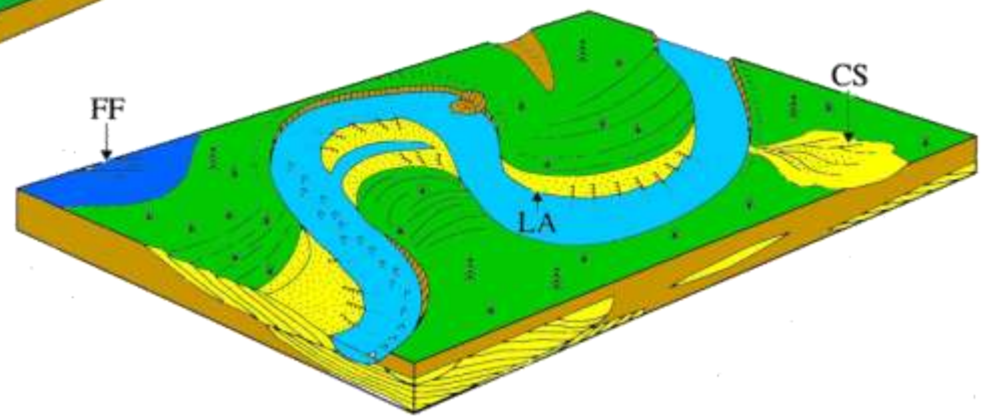


Fluvial Facies Models

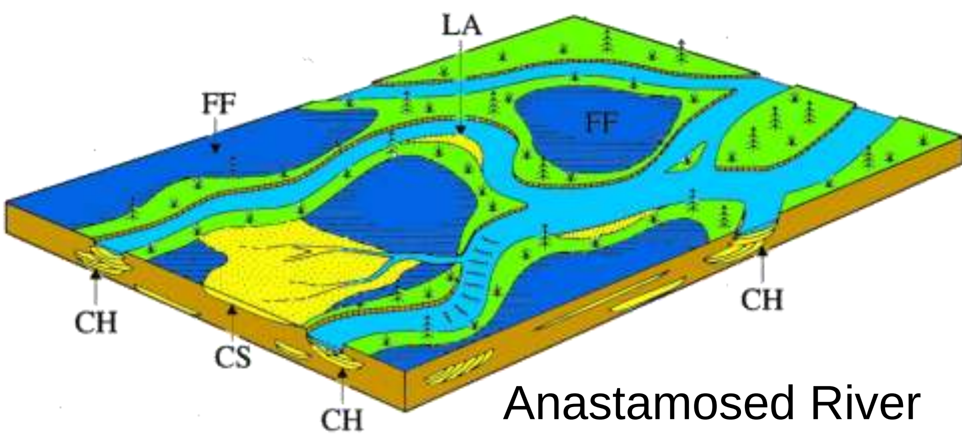
(from Miall 1996)



Sandy Braided River



Sandy Meandering River



Anastamosed River

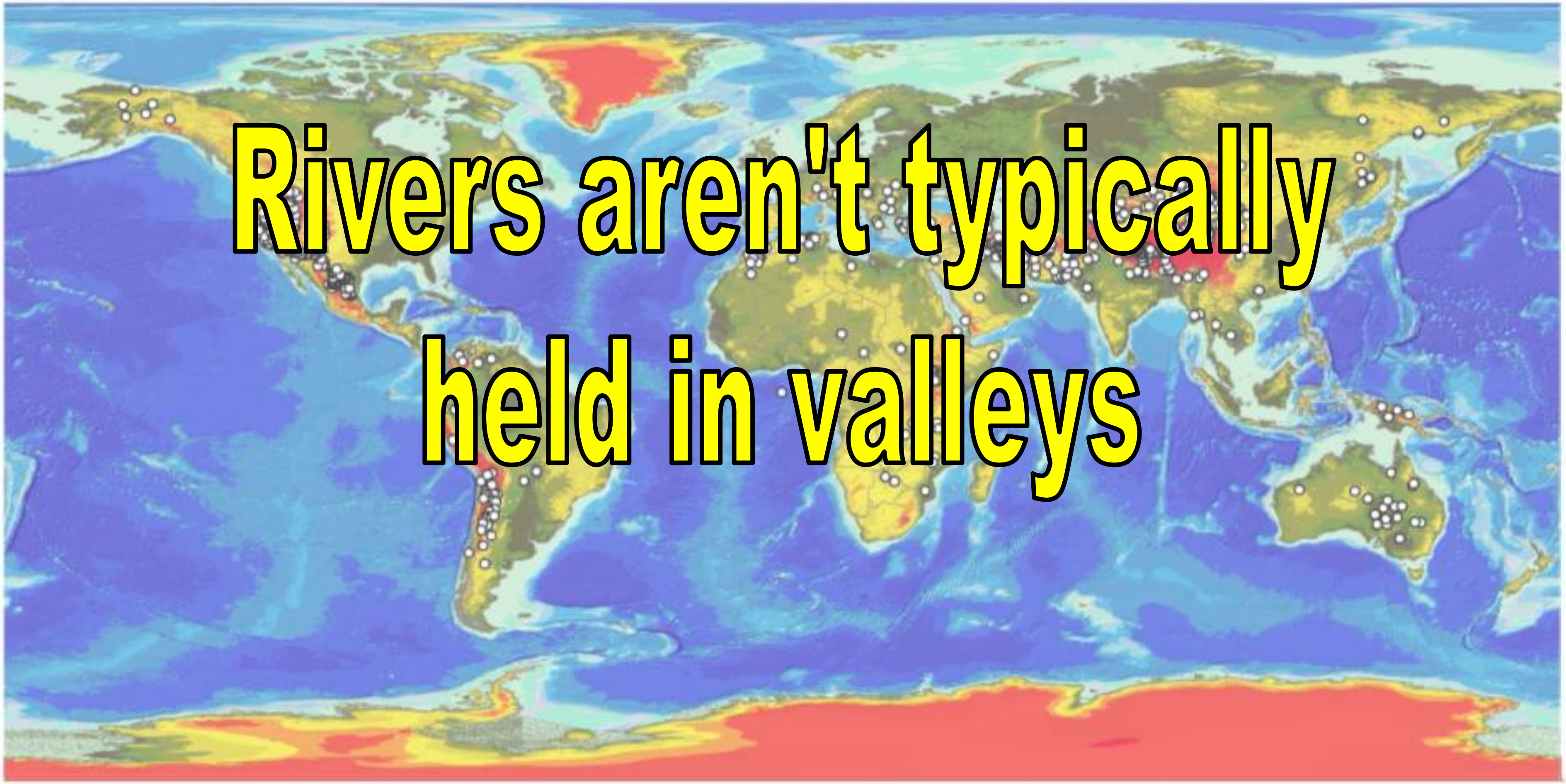
Floodplains???

Fundamental Principle of Sedimentary Geology:

Sedimentary rocks are formed from deposits in ancient sedimentary basins!

Morrison Formation, New Mexico

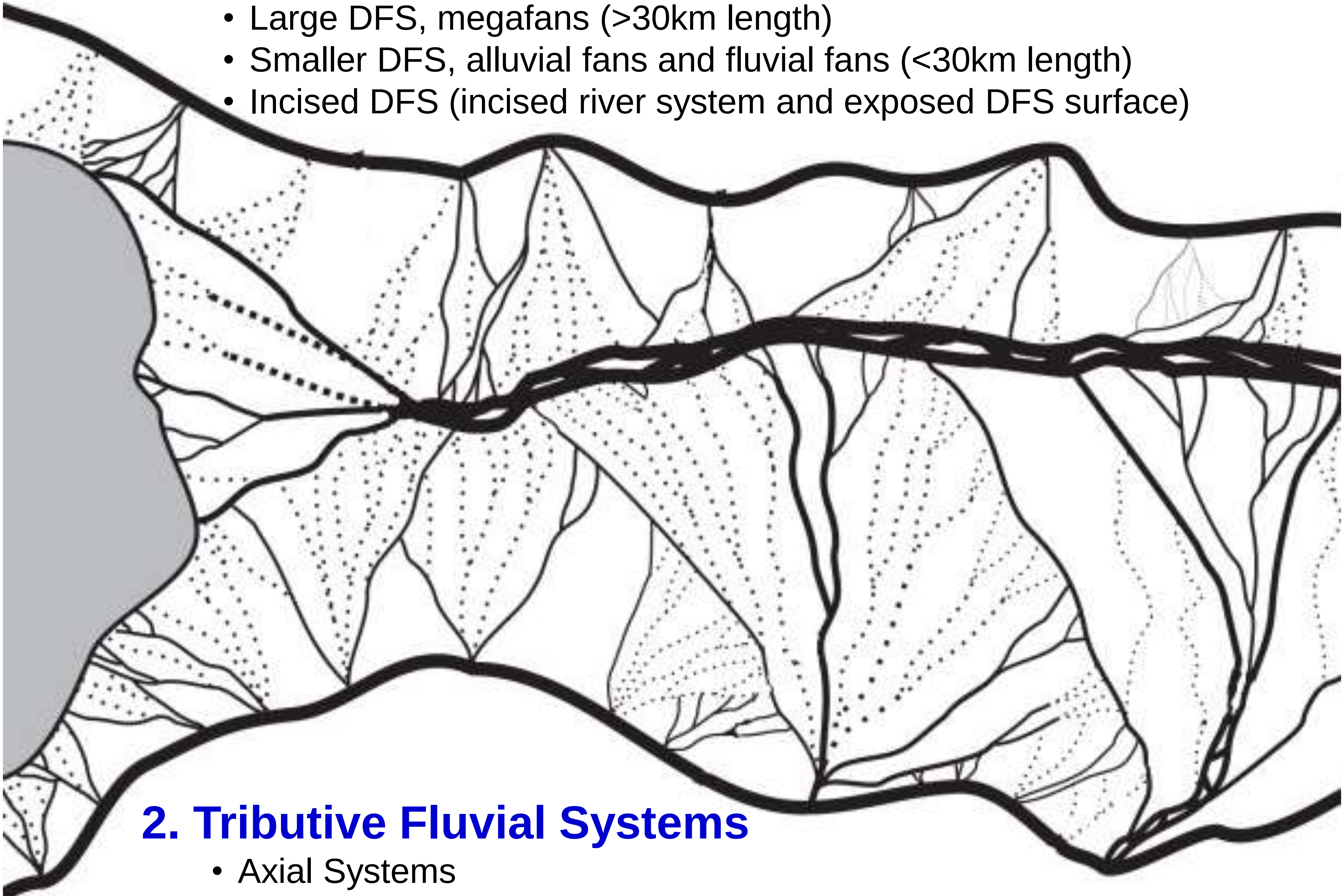
A review of ~700 modern continental sedimentary basins provides a different picture.



Weissmann et al 2010

1. Distributive Fluvial Systems (DFS)

- Large DFS, megafans (>30km length)
- Smaller DFS, alluvial fans and fluvial fans (<30km length)
- Incised DFS (incised river system and exposed DFS surface)



2. Tributive Fluvial Systems

- Axial Systems
- Interfan tributary systems

Weissmann et al 2010

“Distributive Fluvial Systems” (DFS)

“the *deposit* of a fluvial system which in planform displays a radial distributive channel pattern” (Hartley et al. 2010).

These are megafans, fluvial fans, and alluvial fans (Distributive Fluvial *Landforms*)

Use of term Distributive Fluvial System

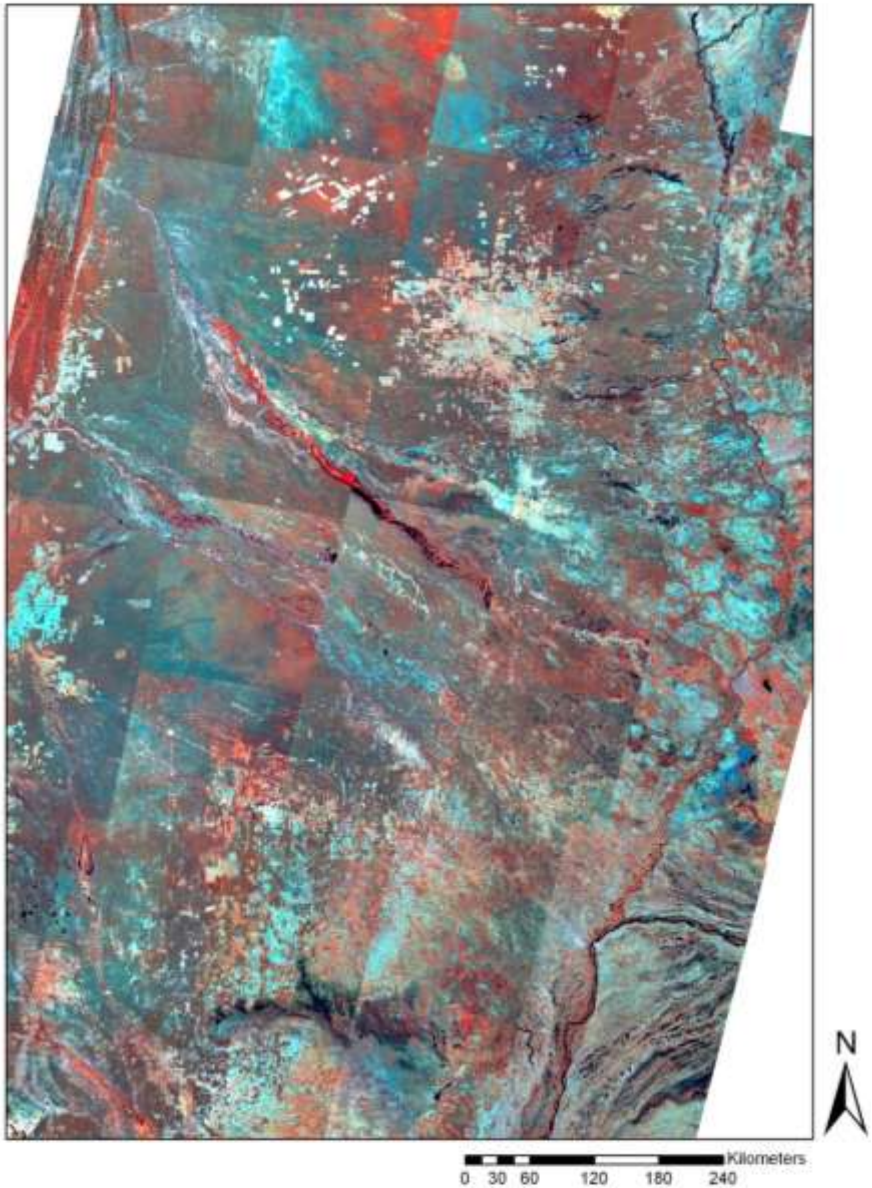
- **Confusion between "distributary" and "distributive"**

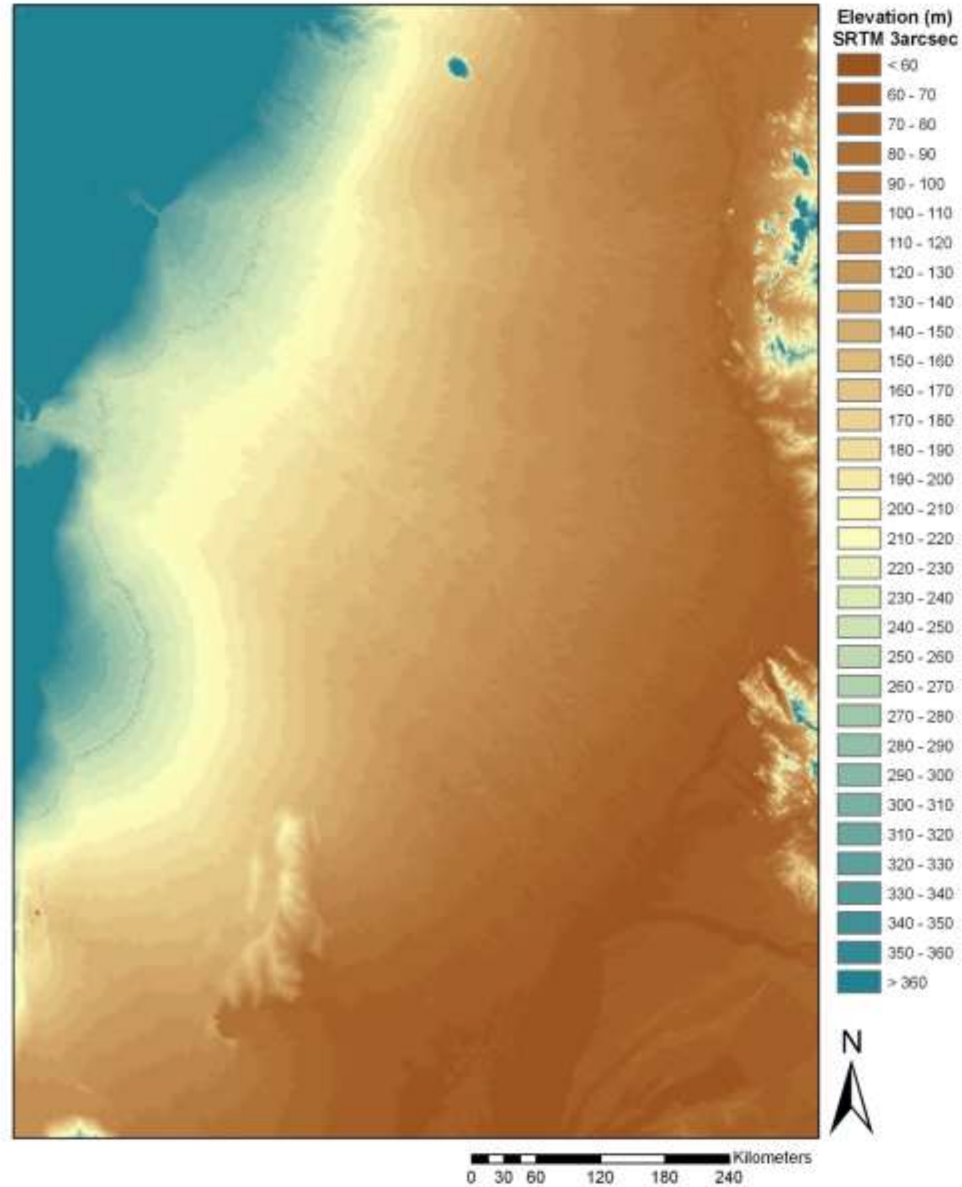
- Definitions from The New Shorter Oxford English Dictionary, 1993, p. 707-708**.**

  - **Distributary**: "1. Distinct, several; 2. That distributes; *spec.* designating a distributary of a canal, river, etc.
    - **Implies multiple channels simultaneously active.**

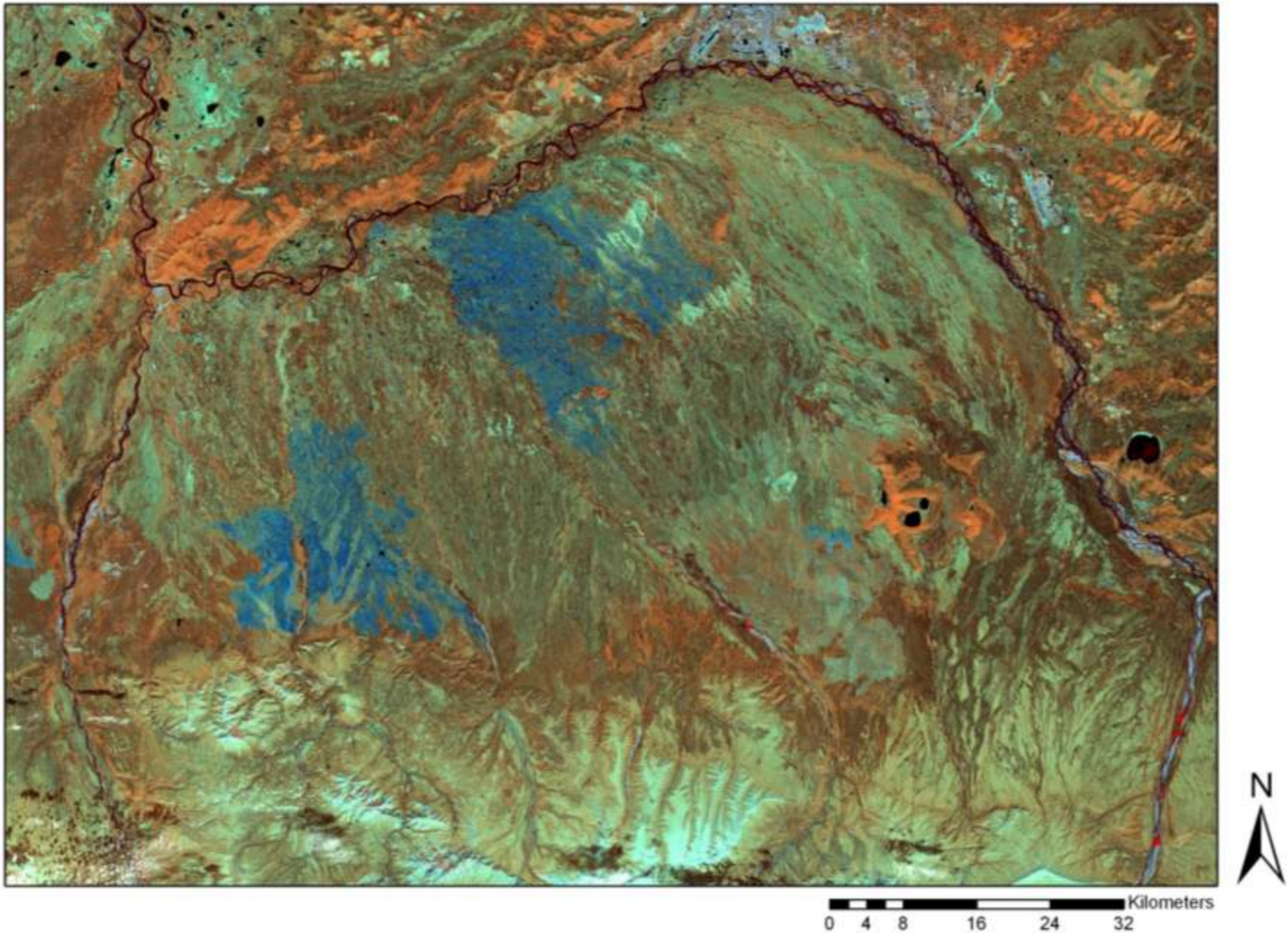
  - **Distributive:** "Having the property of distributing; characterized by dealing portions or by spreading; given to engaged in distribution.".
    - **No implication for multiple channels**.

Andean Foreland Basin, Argentina, Bolivia, Paraguay
Pilcomayo, Bermejo, and Salado Rivers

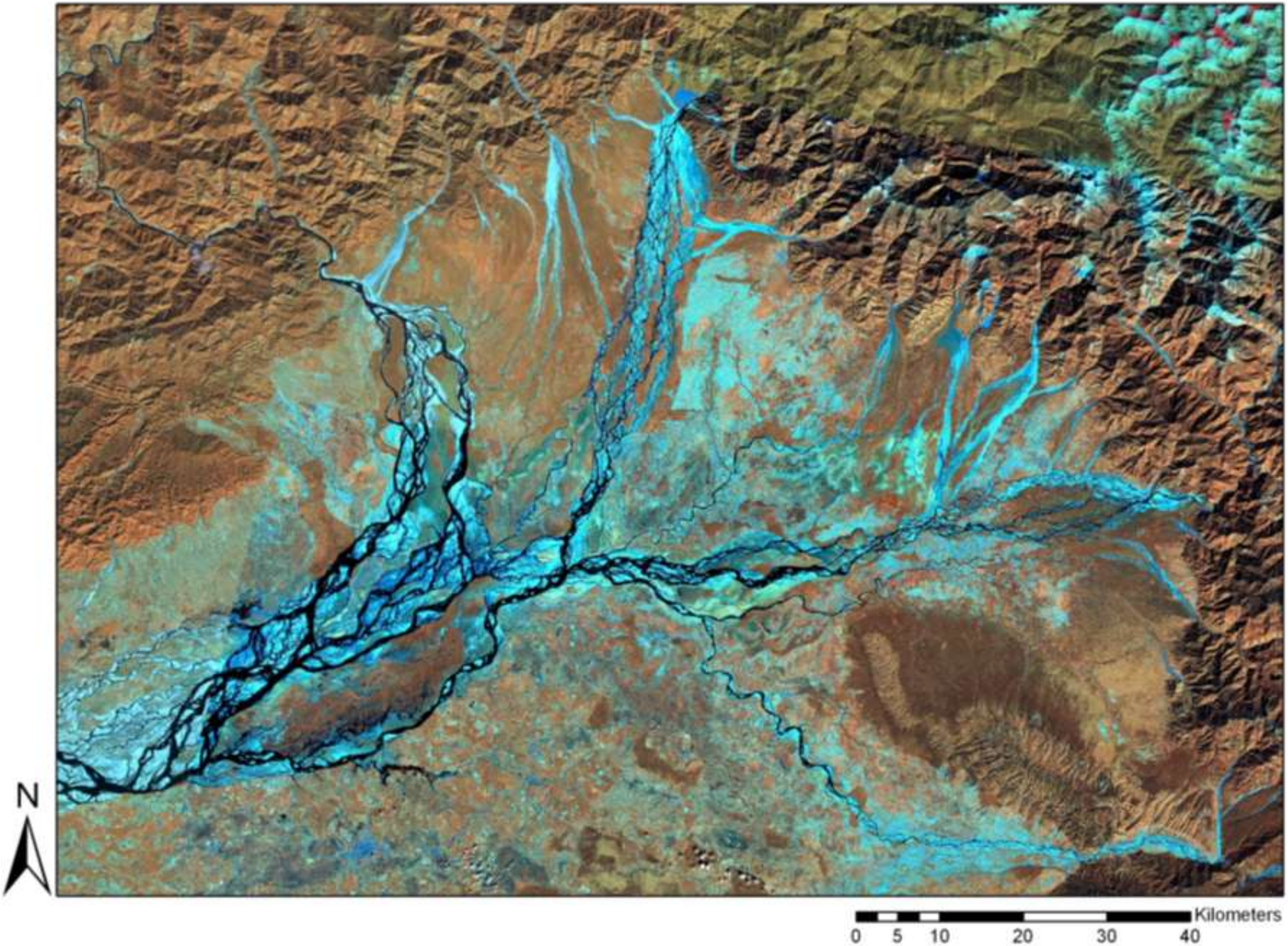




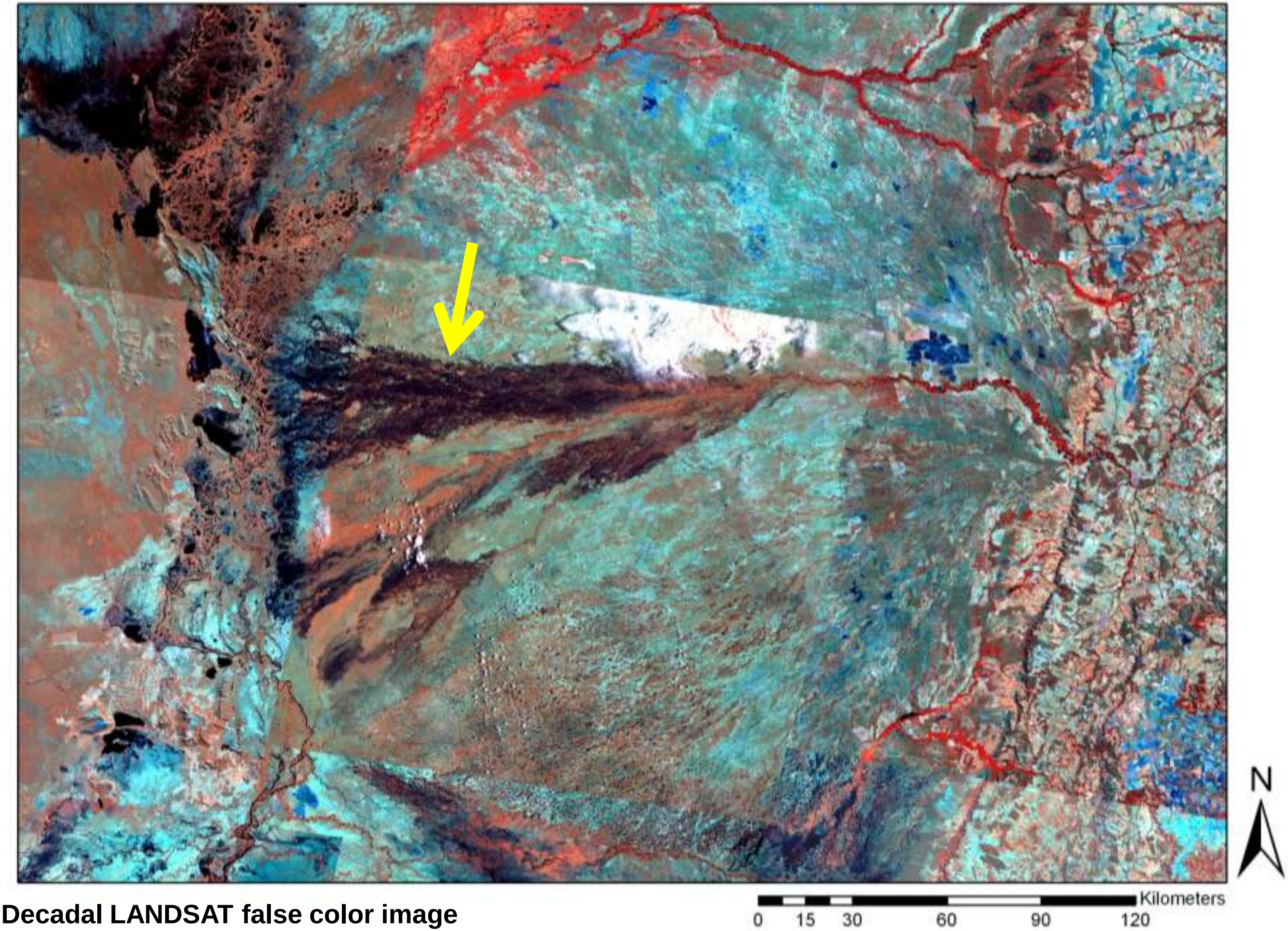
Alaska Range Foreland Basin, Alaska, USA



Upper Brahmaputra River, Himalayan Foreland Basin, India

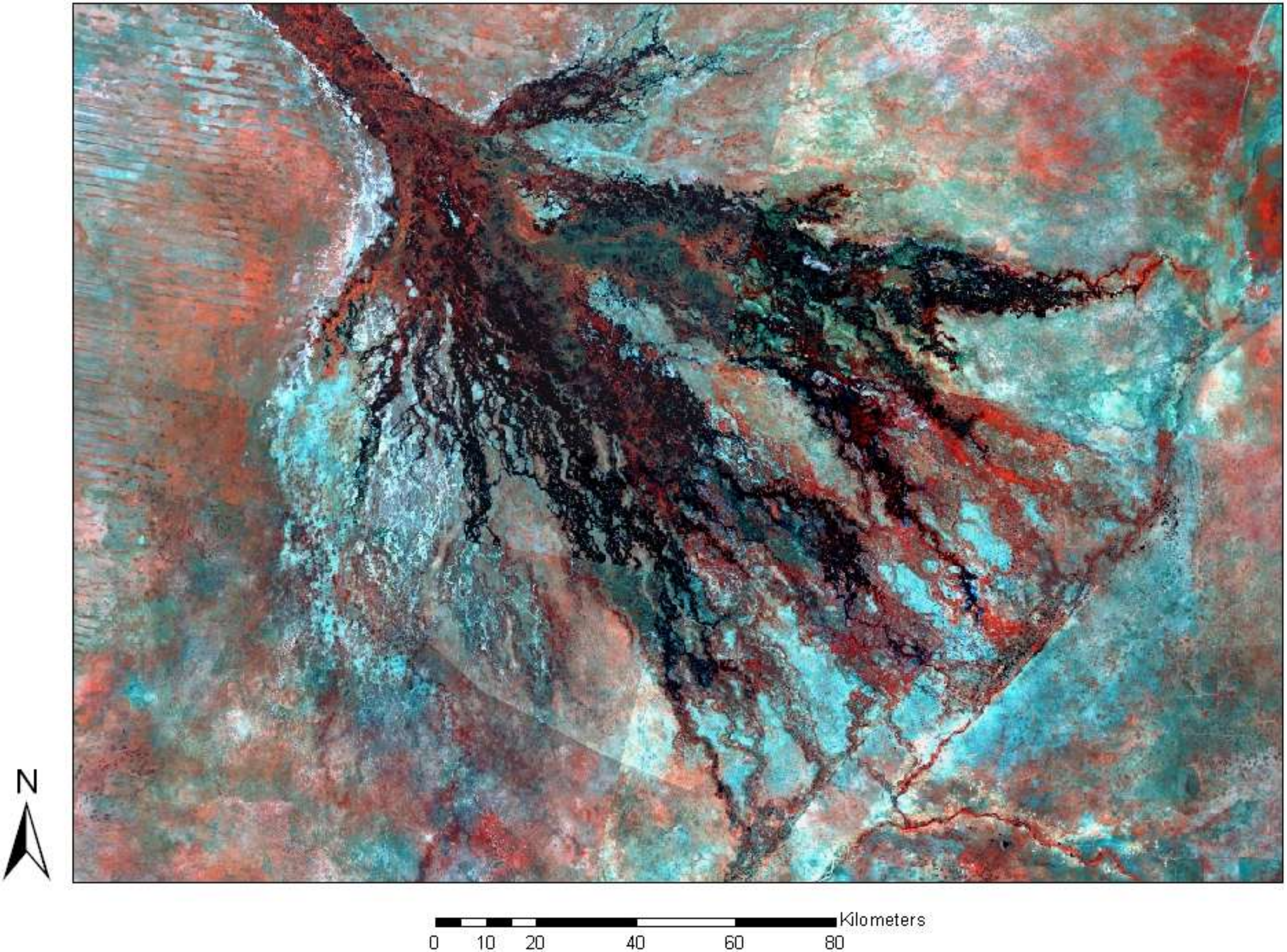


Pantanal Basin, Brazil (Taquari River DFS)

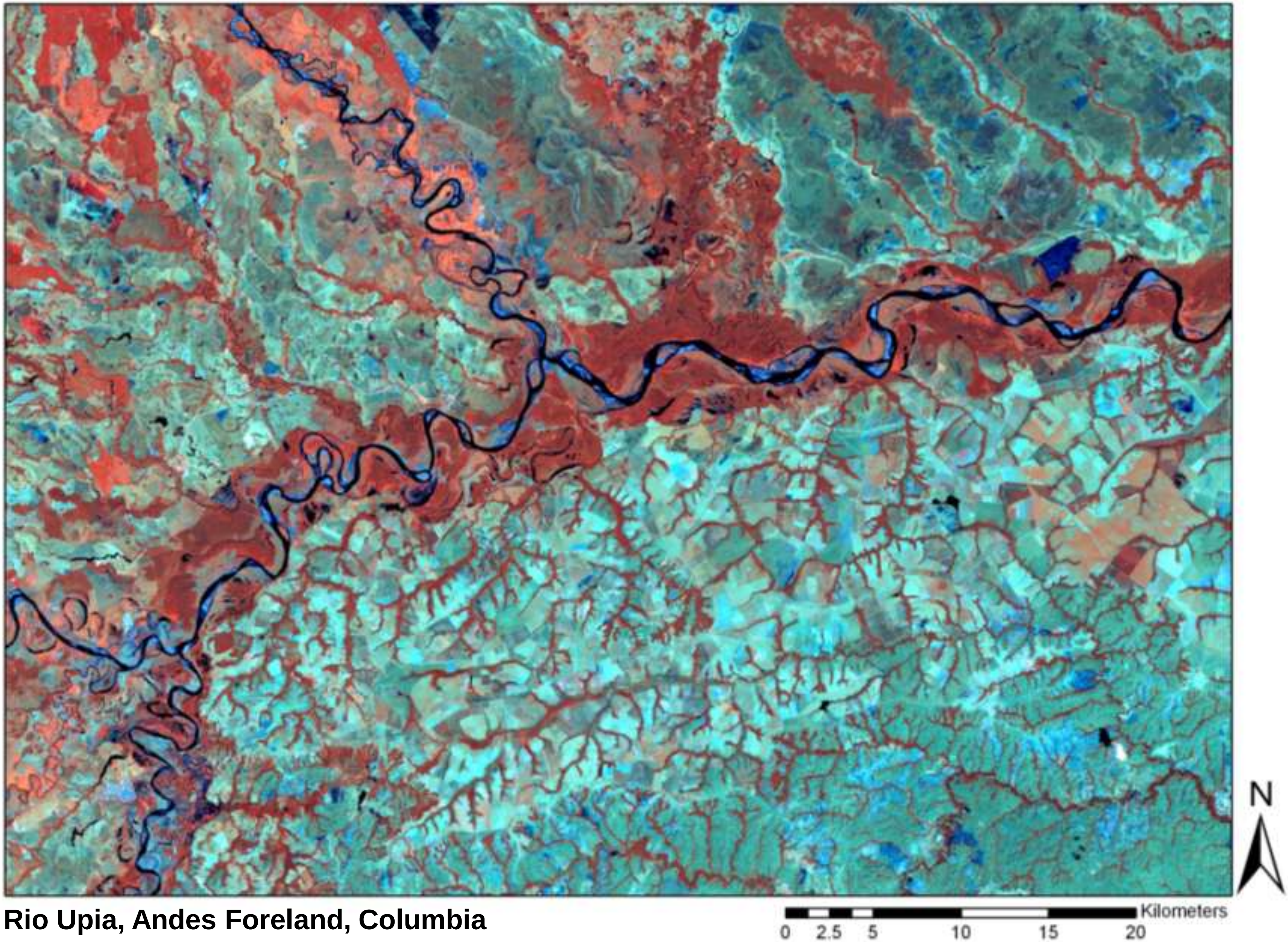


Decadal LANDSAT false color image

Okavango River DFS, Botswana



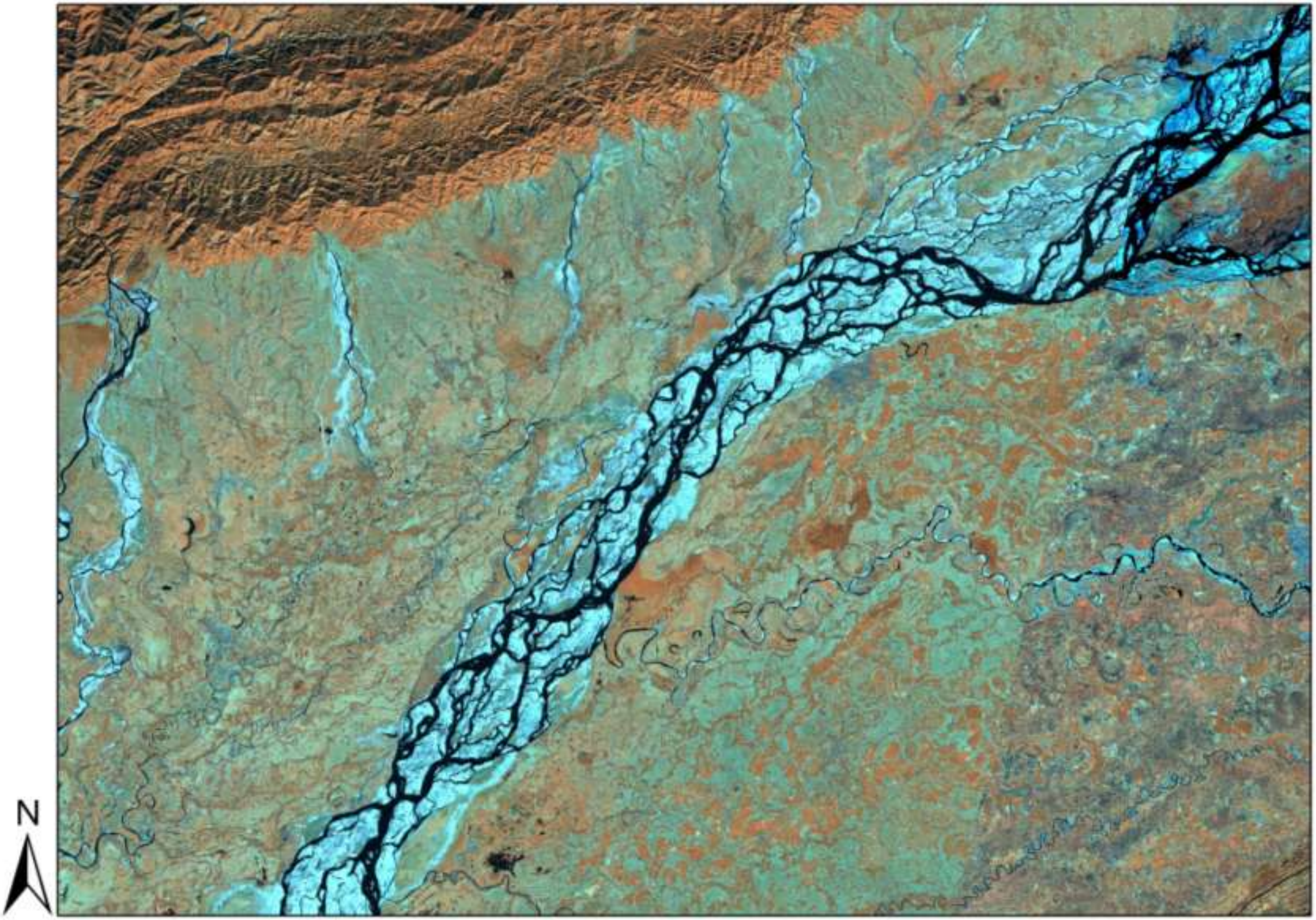
Axial Tributary River Systems



Rio Upia, Andes Foreland, Columbia

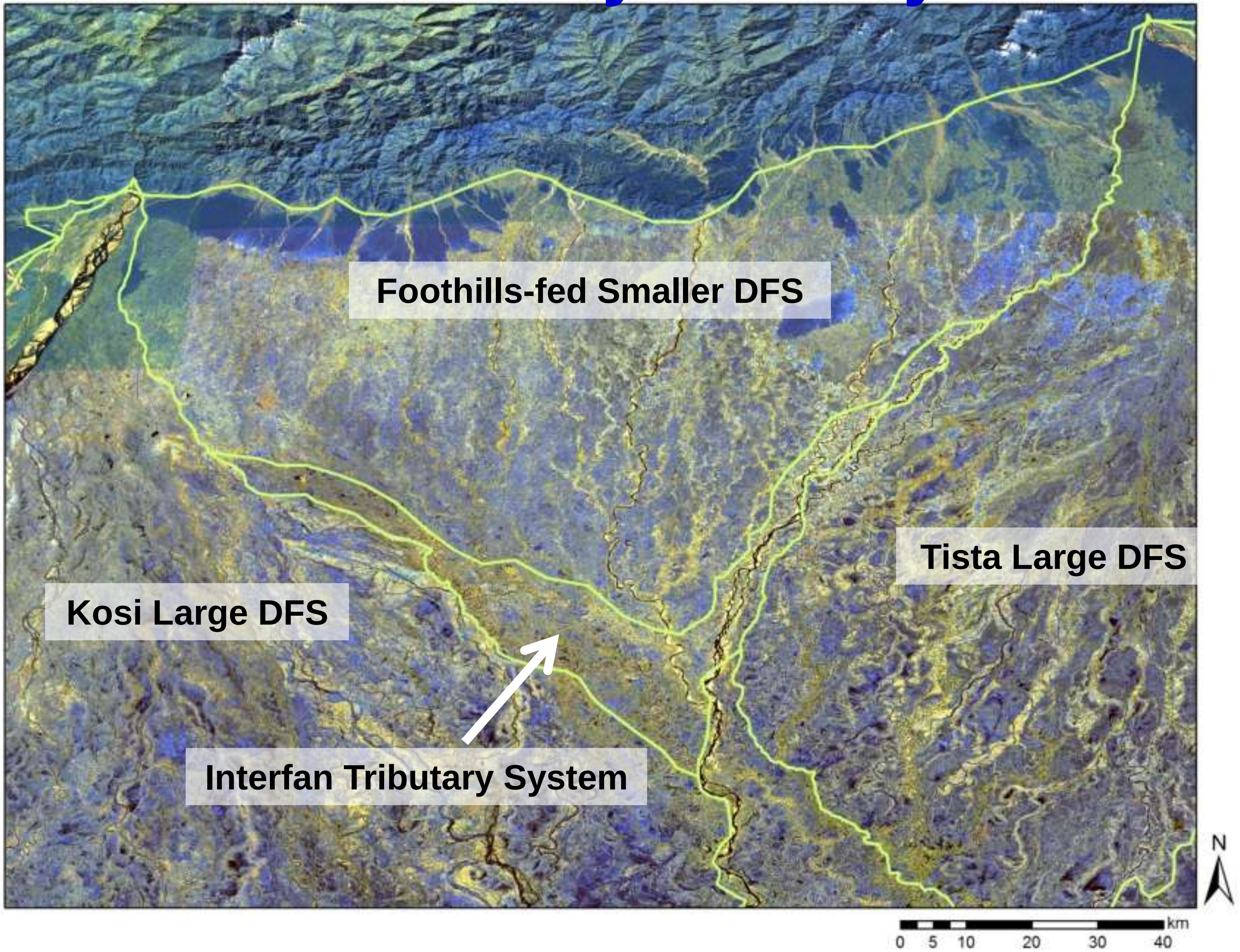
Axial Paraguay River, Andean Foreland Basin

Axial Tributary River Systems

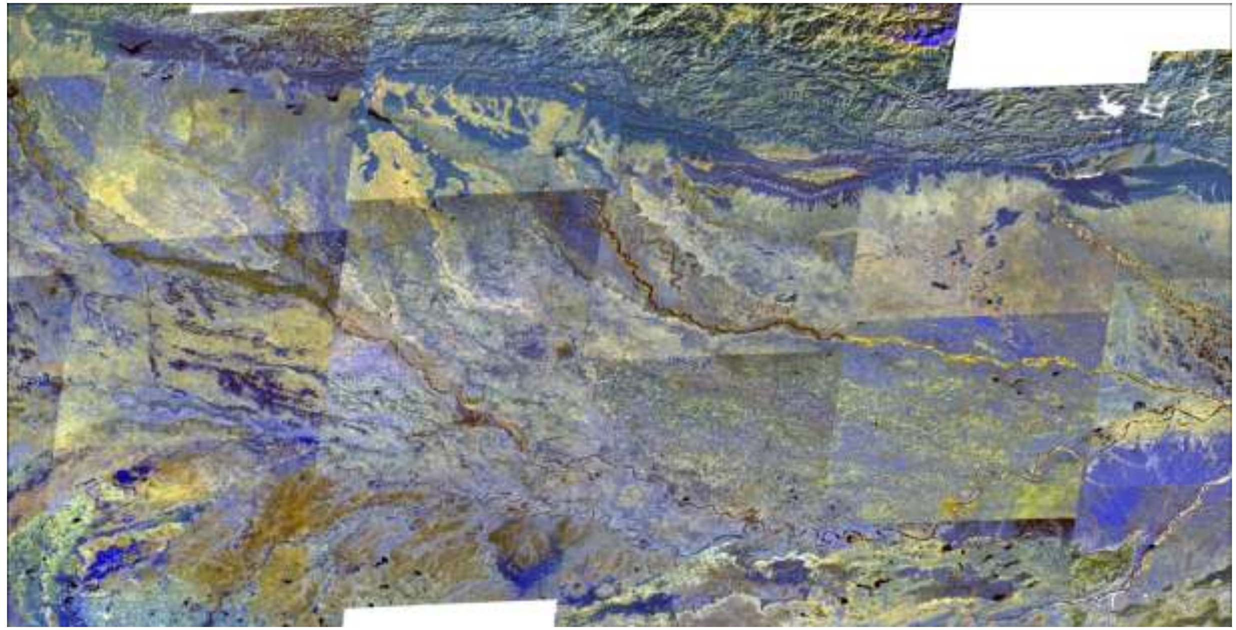


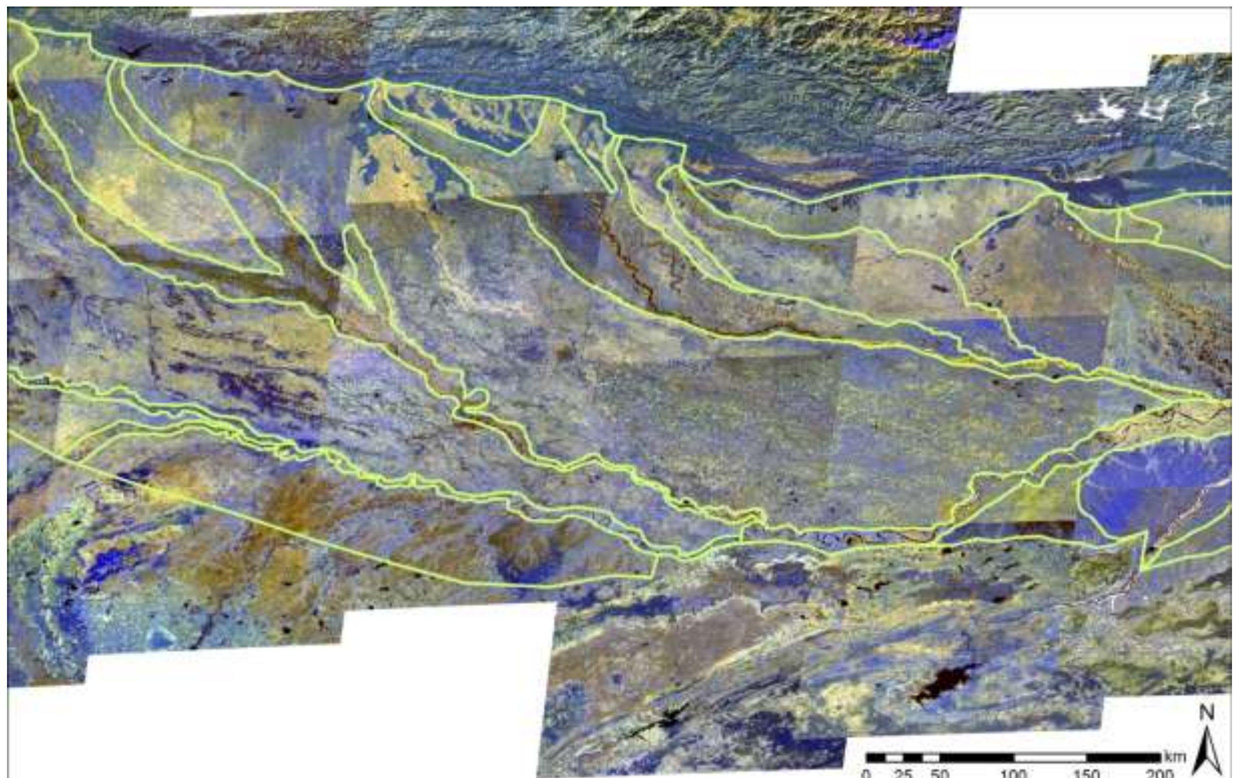
Brahmaputra River, India

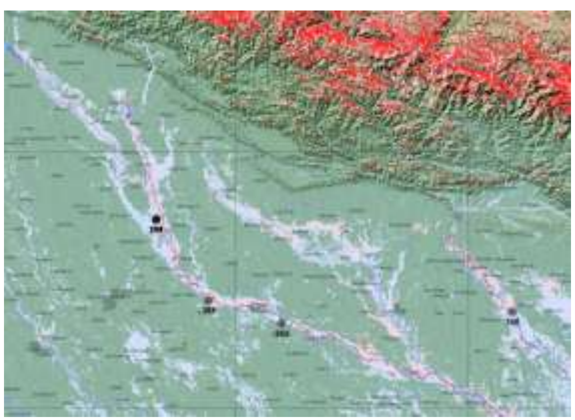
Interfan Tributary River Systems



Incised DFS
Himalayan Foreland Basin







Dartmouth Flood Map,
University of Colorado

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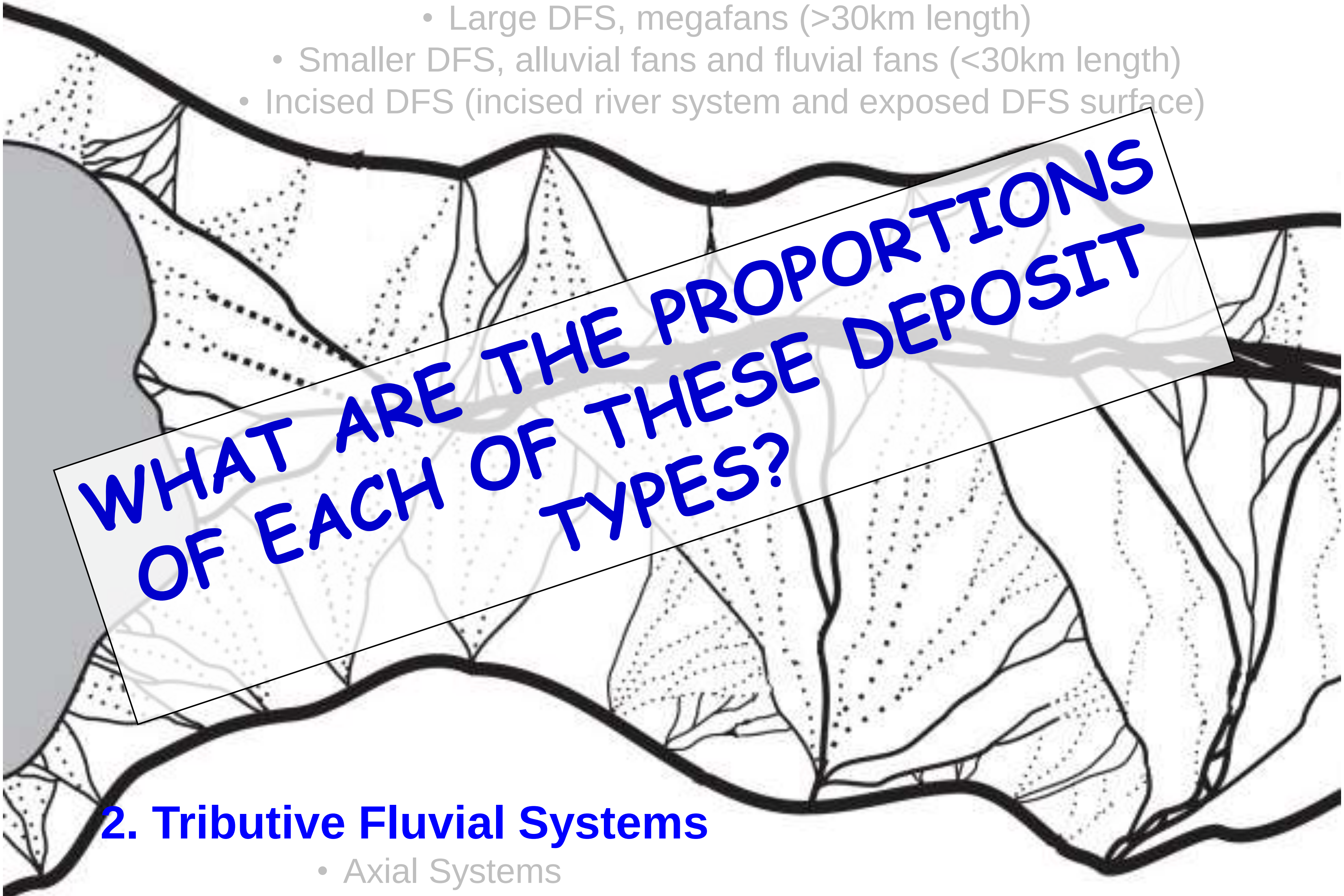

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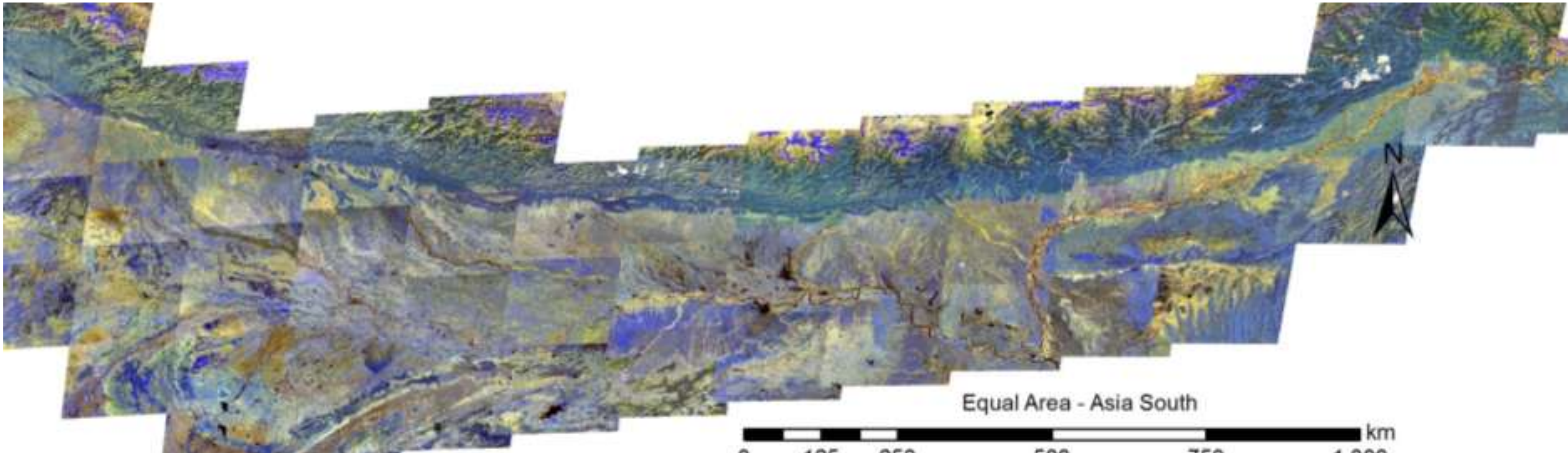
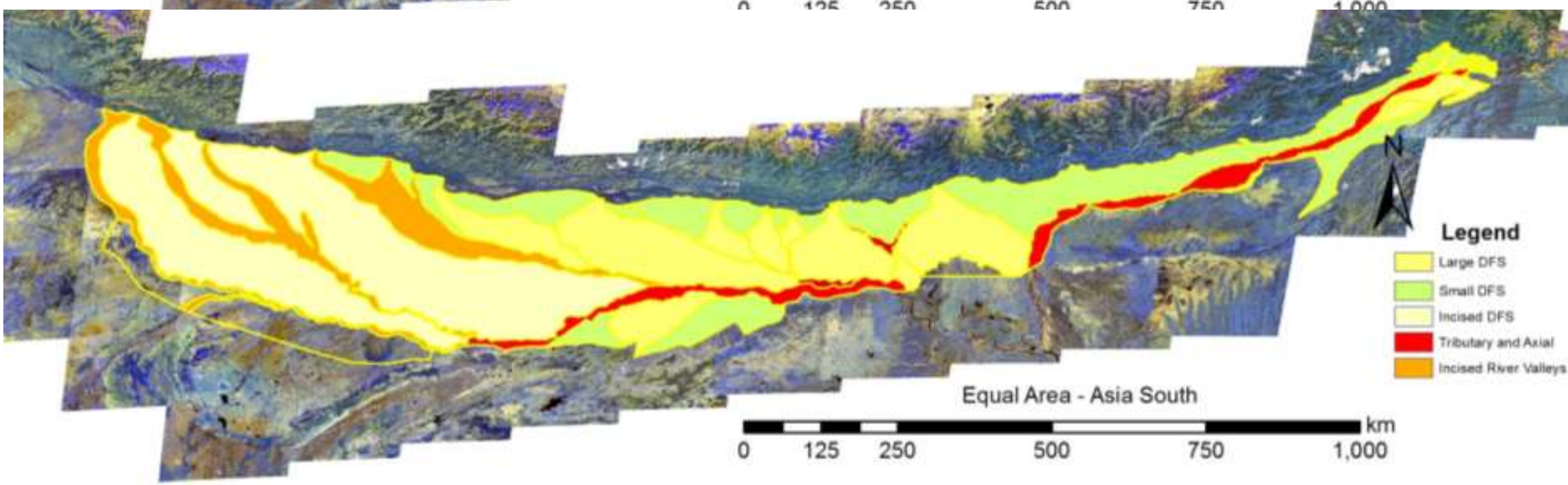
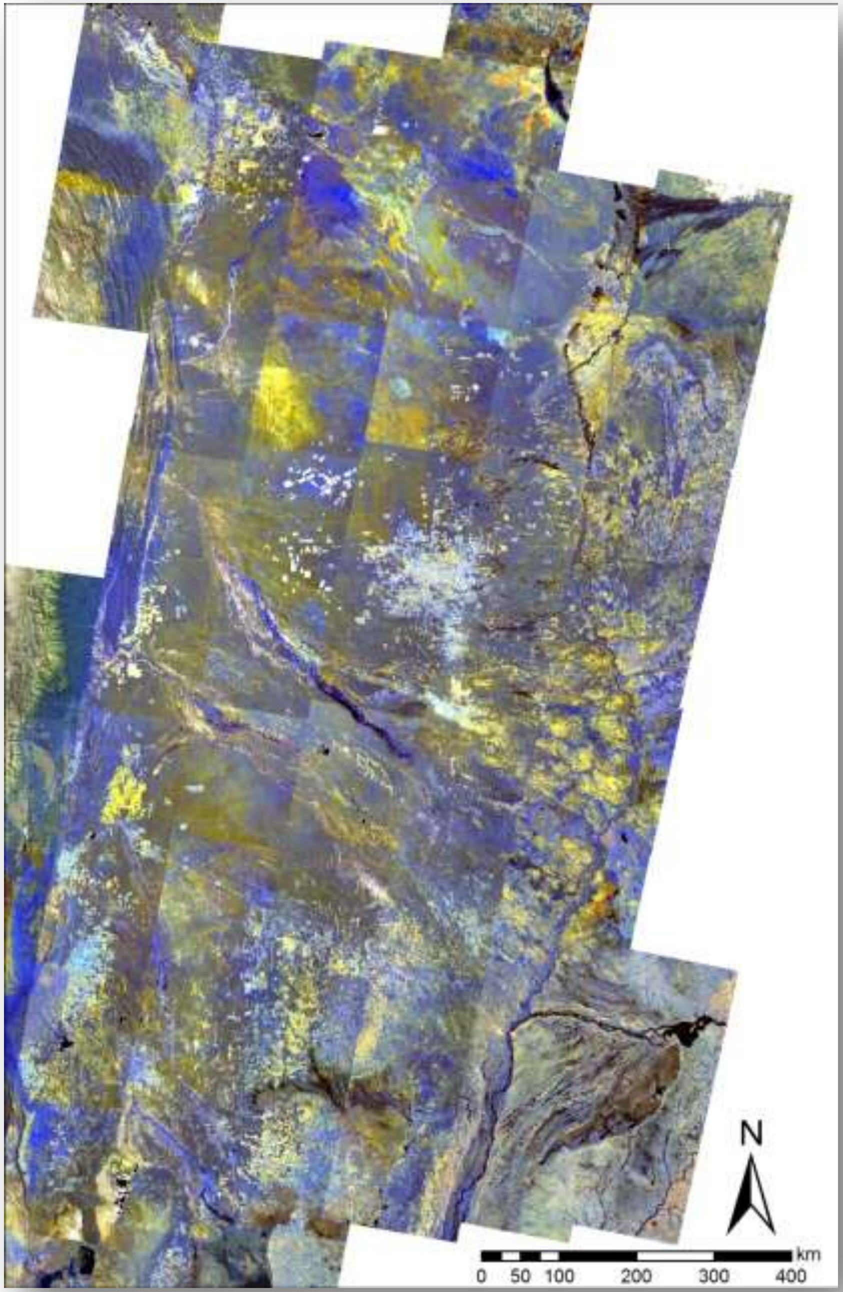
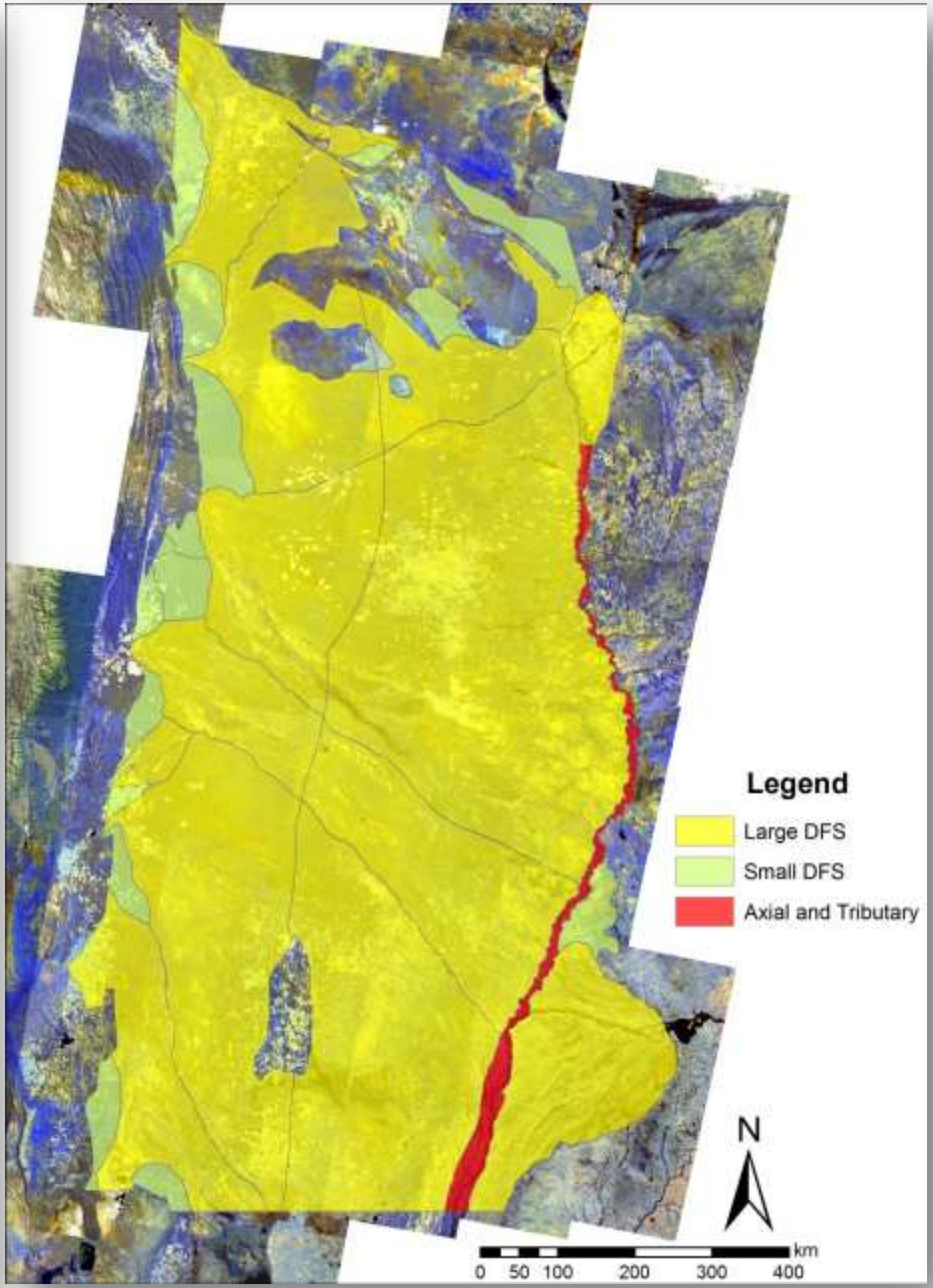
Himalayan Foreland Basin



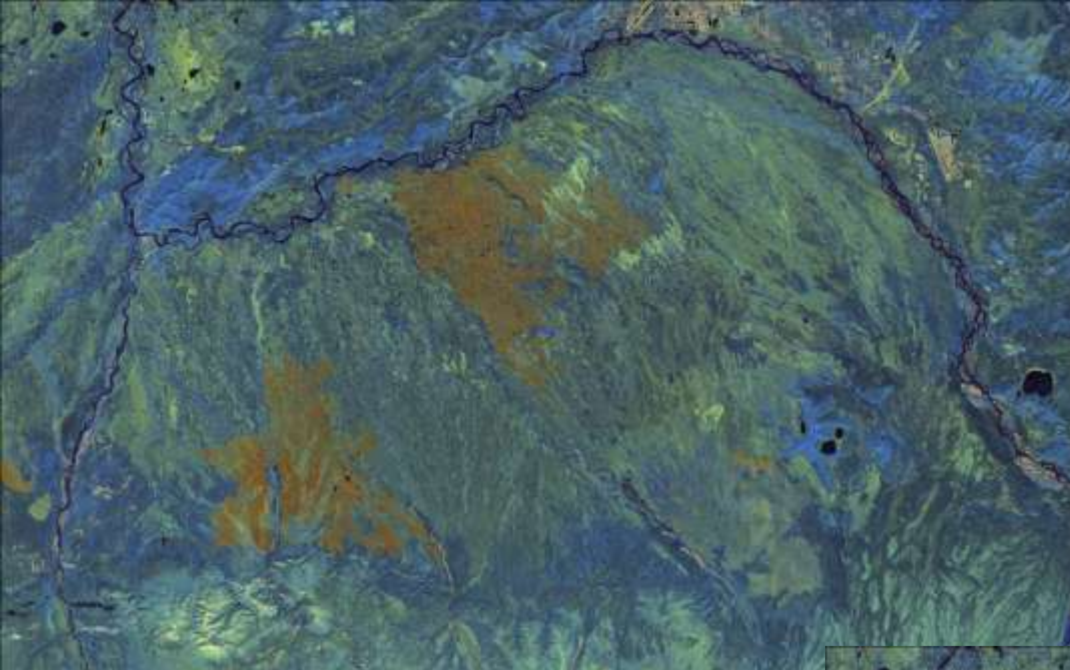


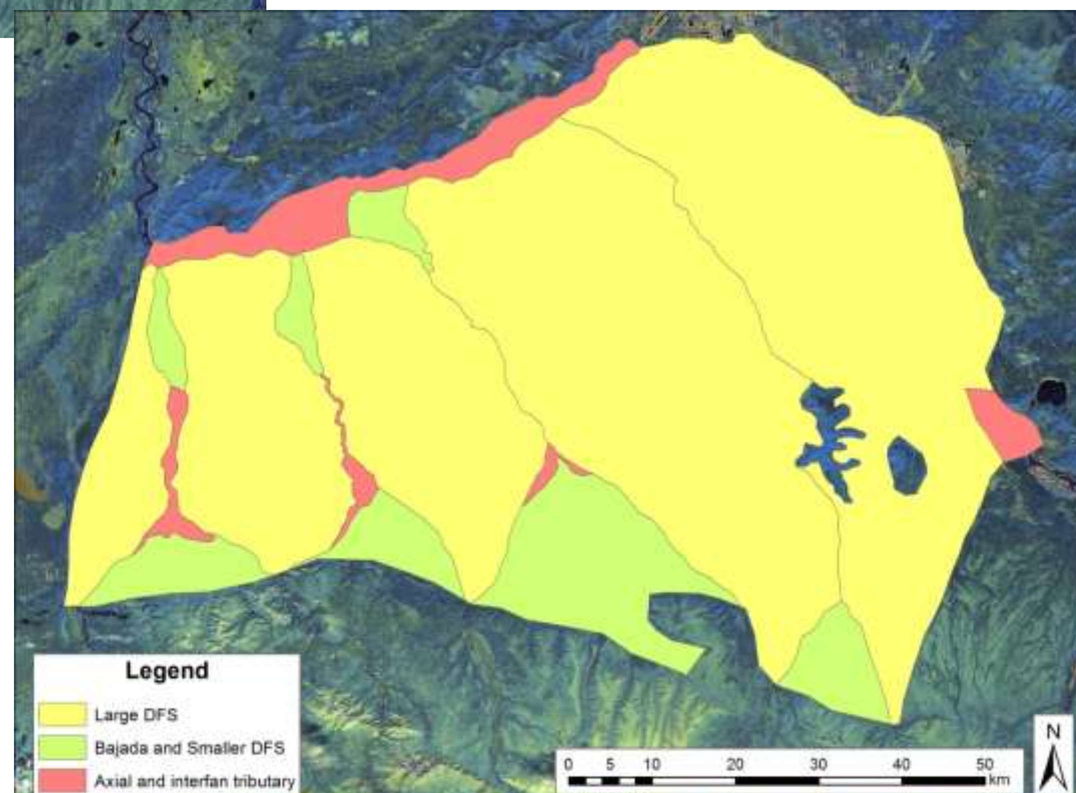
Andes Foreland Basin – Chaco Plain



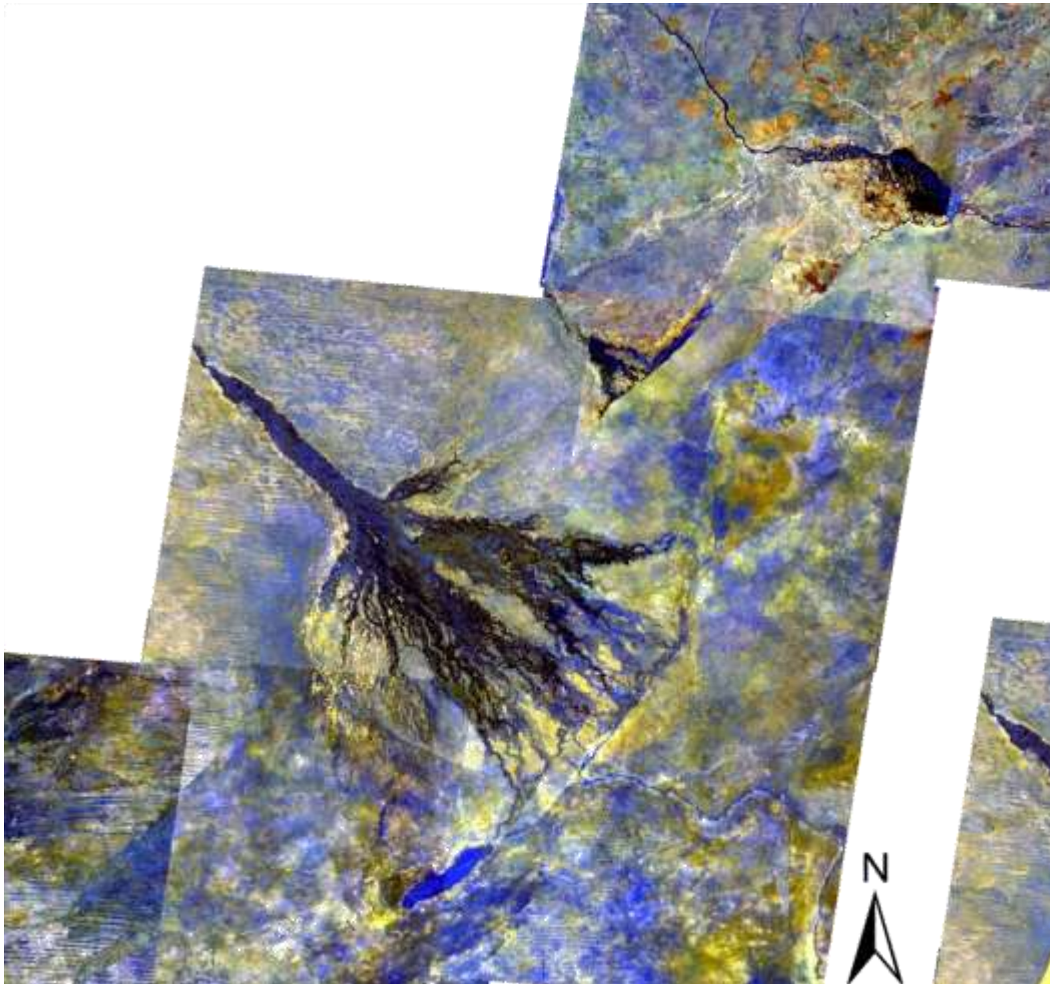


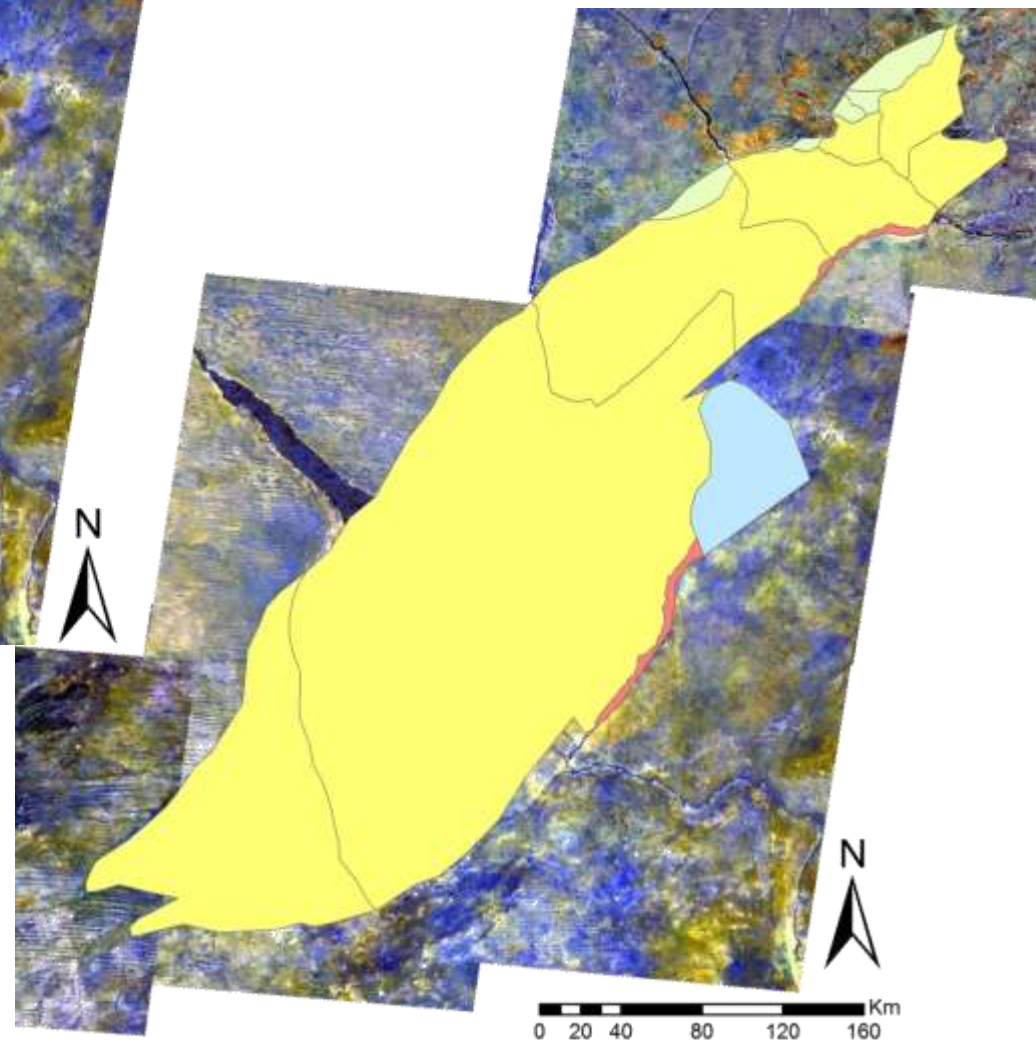
Alaska Range Foreland Basin





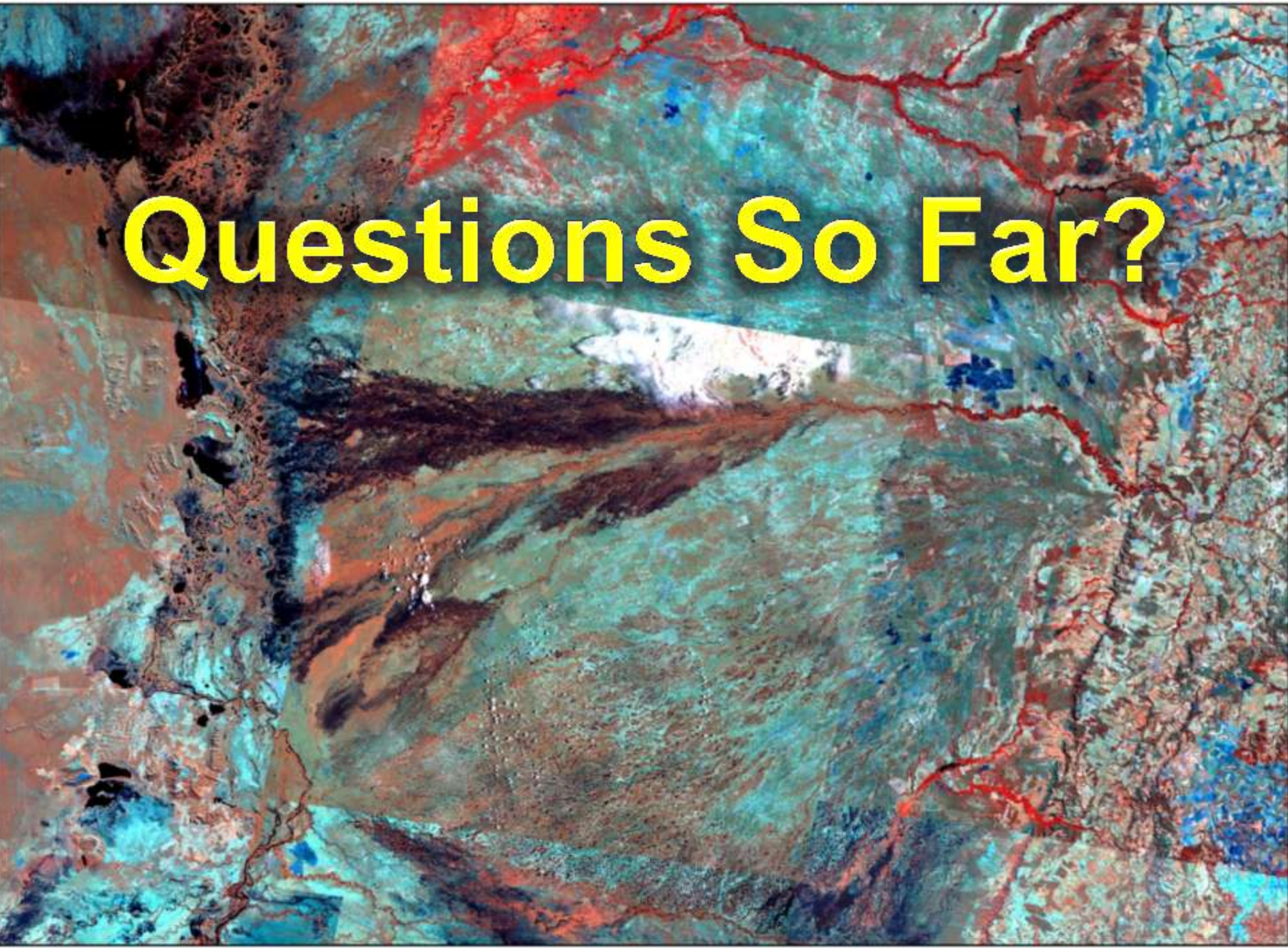
Okavango Rift





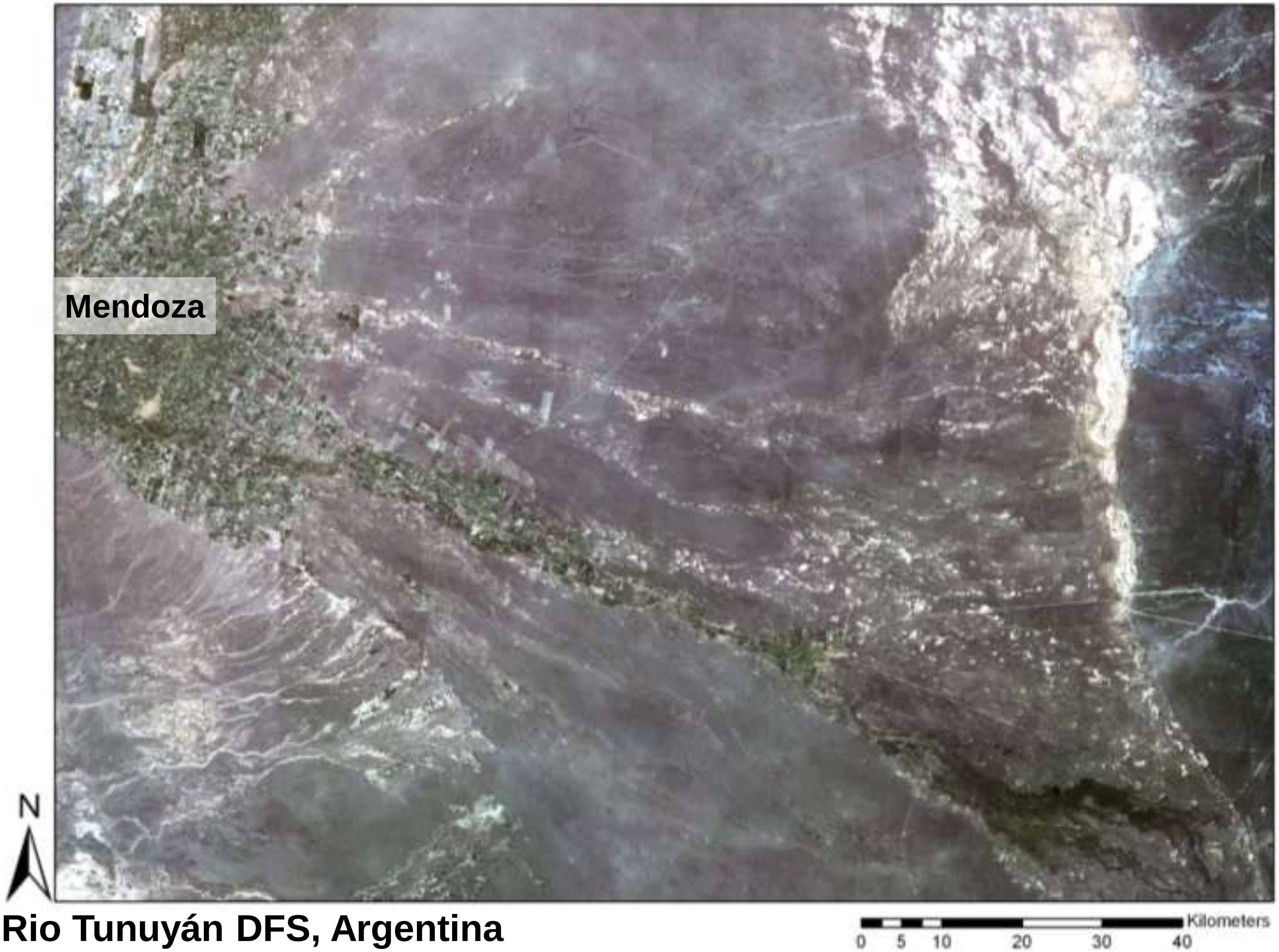
Percent Area Covered by Geomorphic Elements

Basin / Geomorphic Element	Himalayan Foreland	Andean Foreland (Chaco)	Andean Foreland (<250km)	Alaska Range Foreland	Okavango Rift
Megafans	**24.7**	**89.60**	**85.80**	**81.08**	**92.35**
Smaller Fans	**0.7**	**0.94**	**2.13**	**2.15**	**0.23**
Piedmont / Bajadas	**22.3**	**7.45**	**11.87**	**11.20**	**1.94**
Abandoned megafan surfaces	**33.9**	--	--	--	--
Incised Valleys into fans	**11.2**	--	--	--	--
Axial Rivers	**6.6**	**1.84**	--	**4.38**	**0.93**
Interfan tributary	**0.6**	**0.17**	**0.20**	**1.19**	--
Lakes/other	---	--	--		**4.55**
Total Distributive	**92.8**	**97.99**	**99.80**	**94.43**	**94.52**
Total Tributive	**7.2**	**2.01**	**0.20**	**5.57**	**0.93**


Questions So Far?

Does this matter????

Distinguishing Characteristics of DFS



Rio Tunuyán DFS, Argentina

Rivers on DFS are not the same as those in tributary systems

(Nichols and Fisher 2007; Weissmann et al. 2010, 2011, 2013; Hartley et al. 2010, 2013):

1. Radial pattern of channels from apex;
2. Channel size commonly decreases downstream;
3. Floodplain deposits avulsion dominated;
4. Greater floodplain deposit preservation;
5. Predictable facies distribution patterns;
6. Predictable progradational pattern

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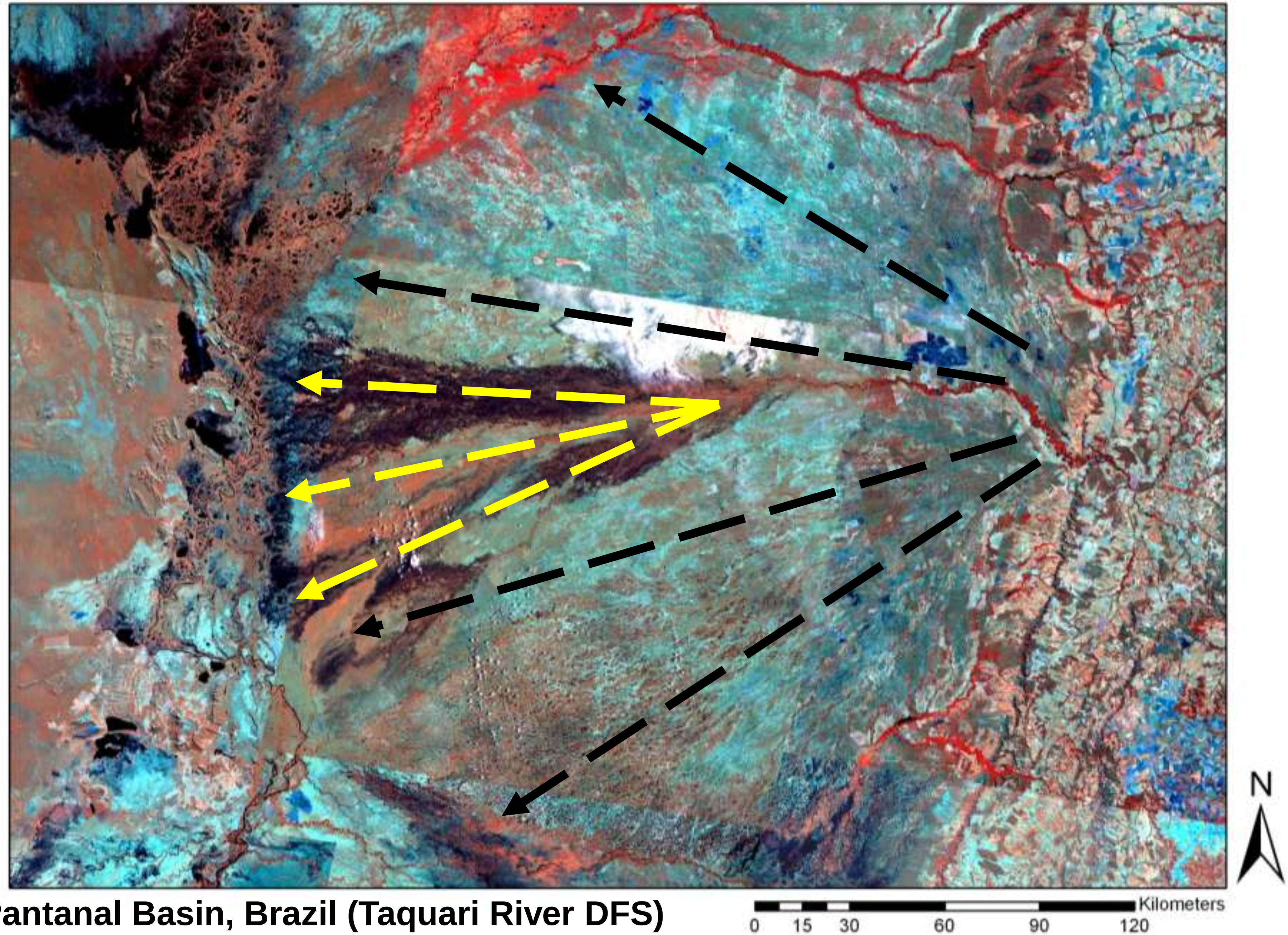

Pantanal Basin, Brazil (Taquari River DFS)

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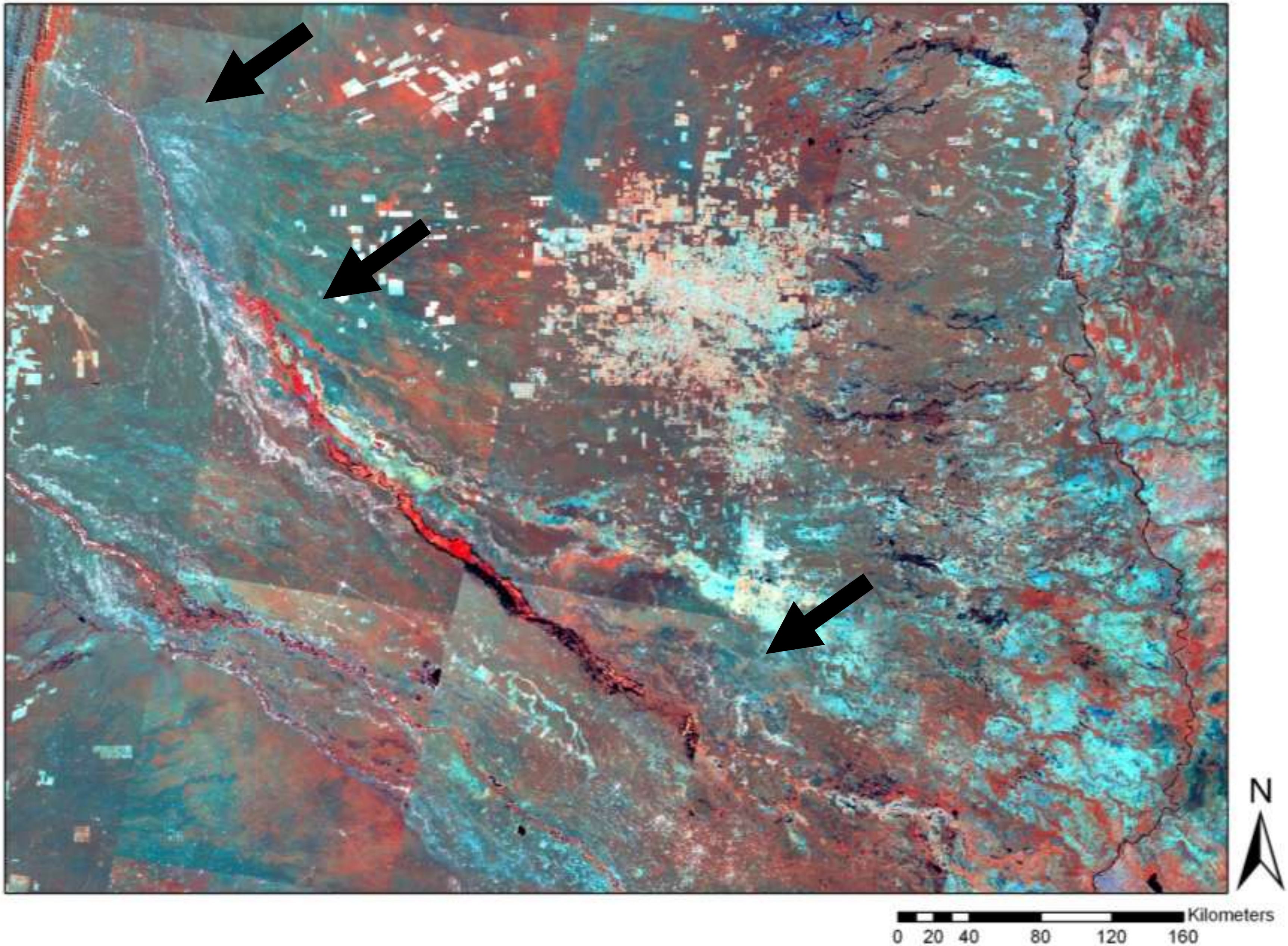
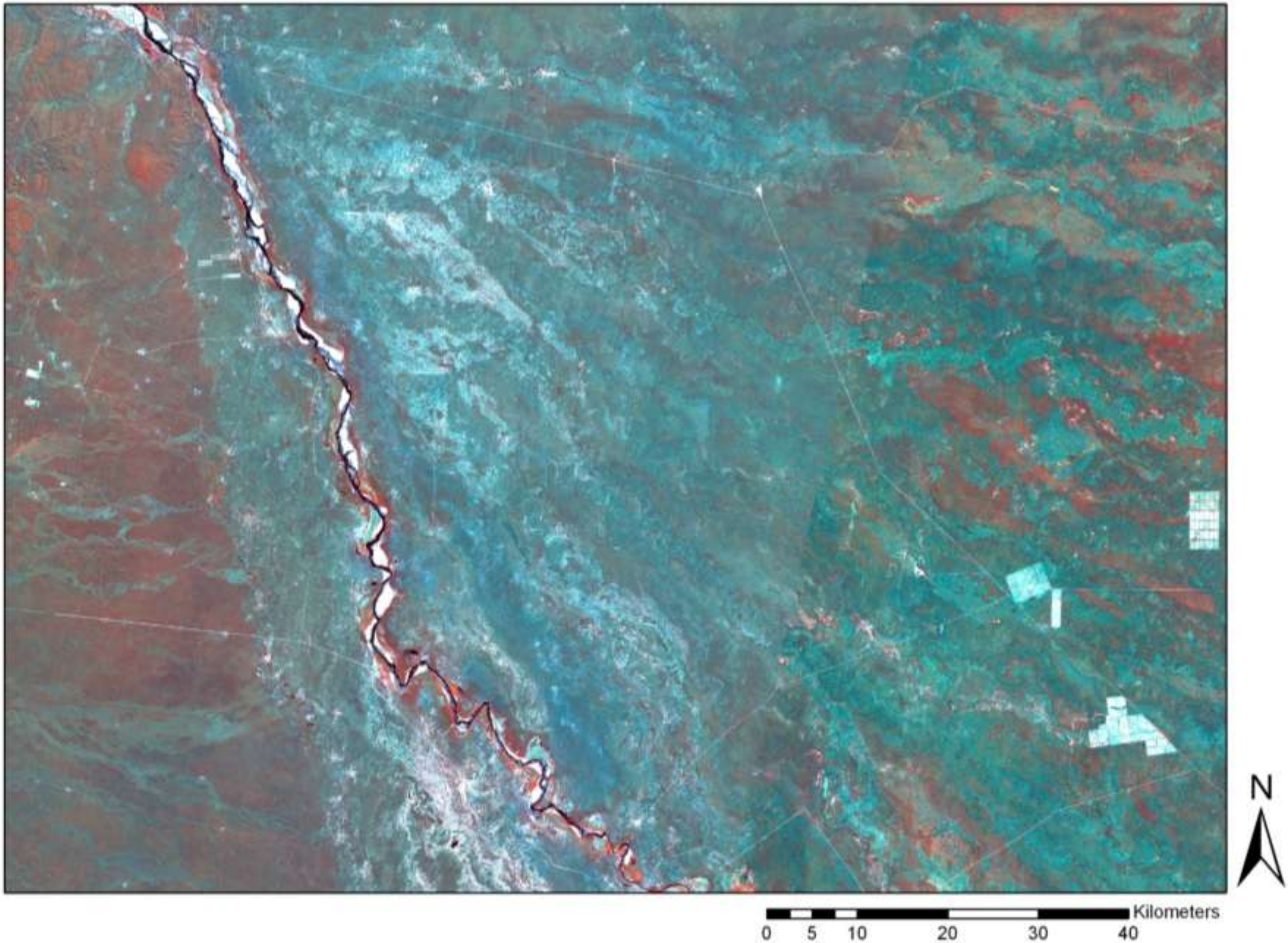
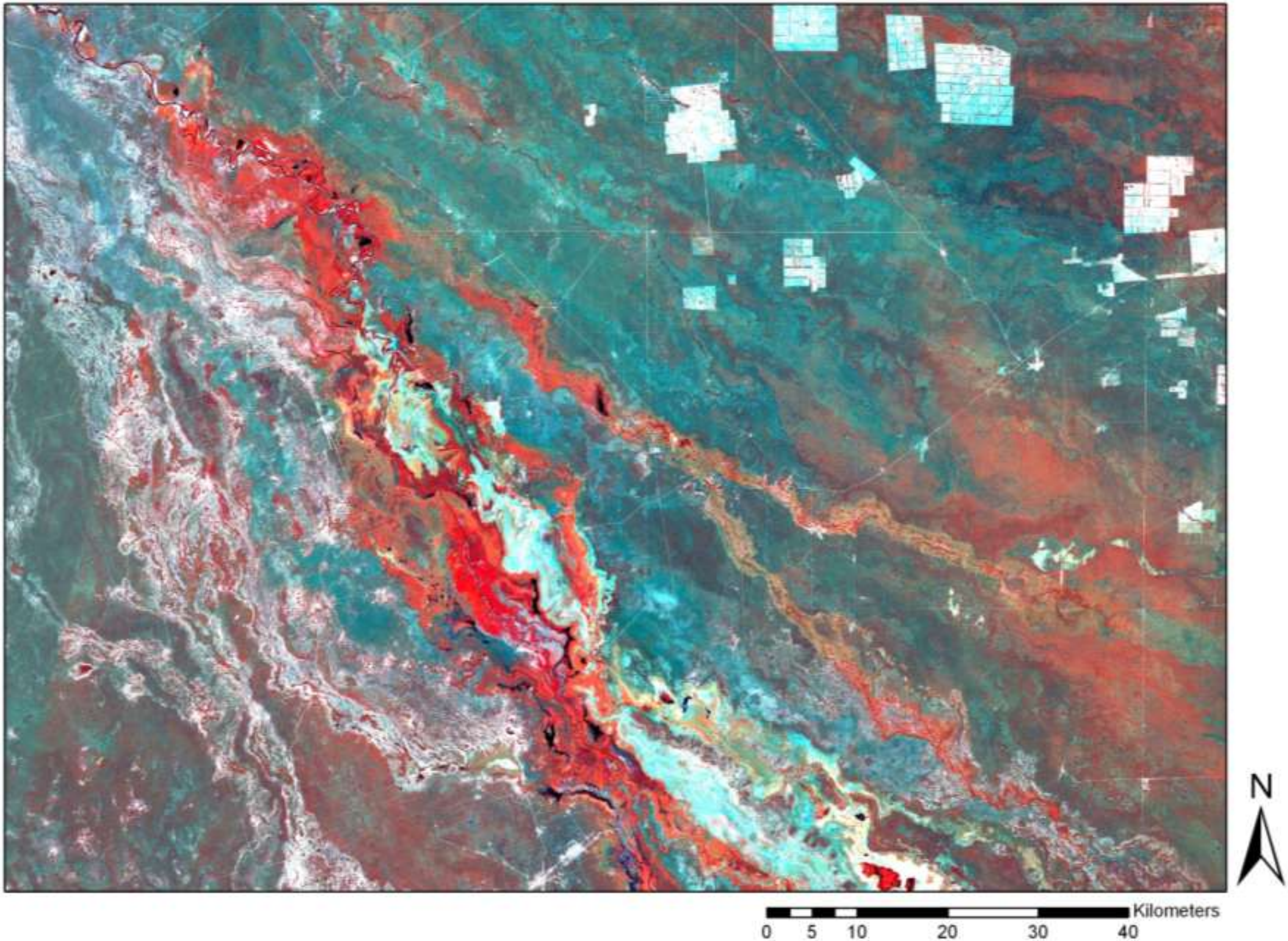
Pilcomayo DFS, Argentina, Bolivia, Paraguay



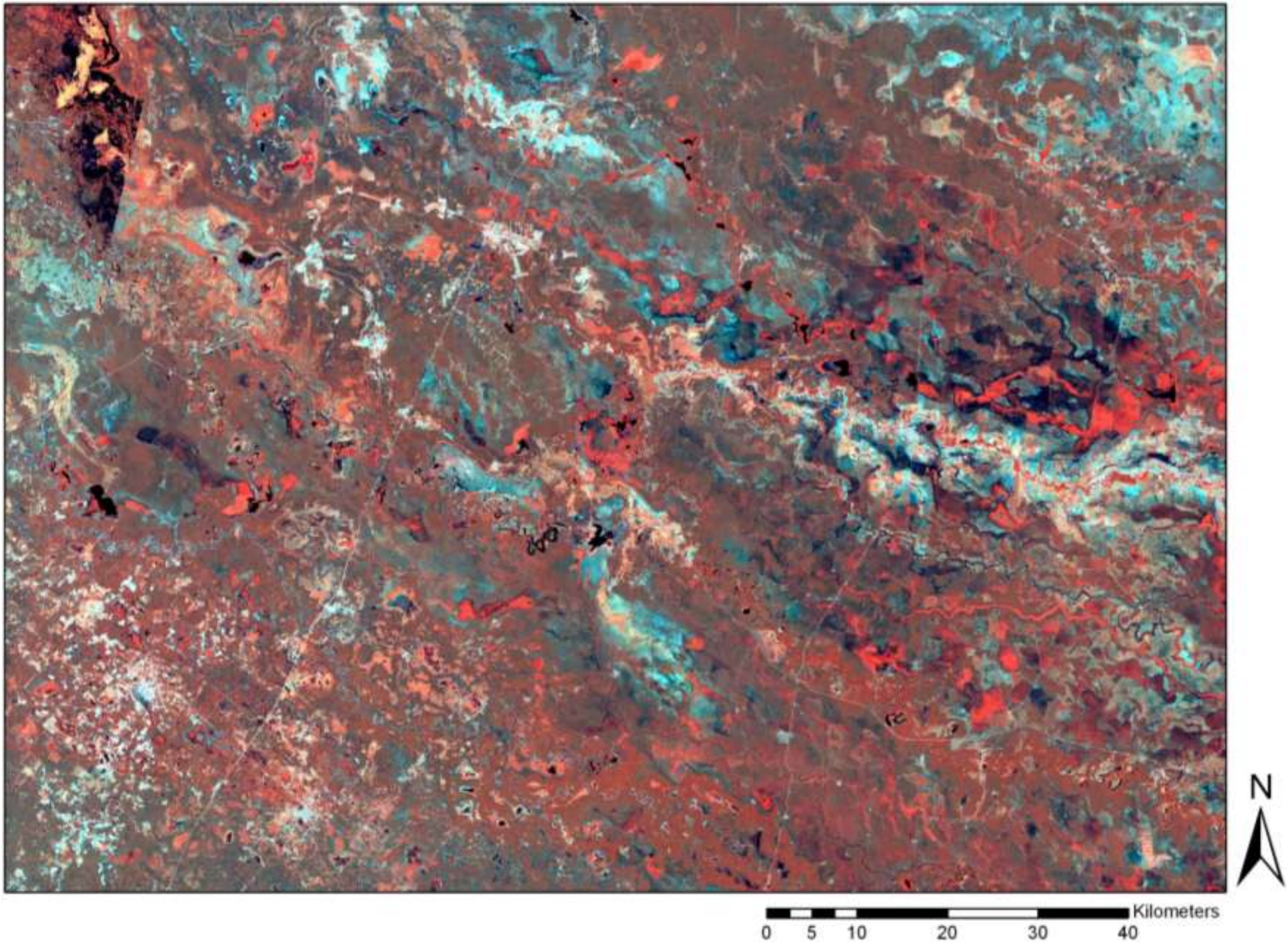
Pilcomayo River, near the apex



Pilcomayo River, medial



Pilcomayo River, distal



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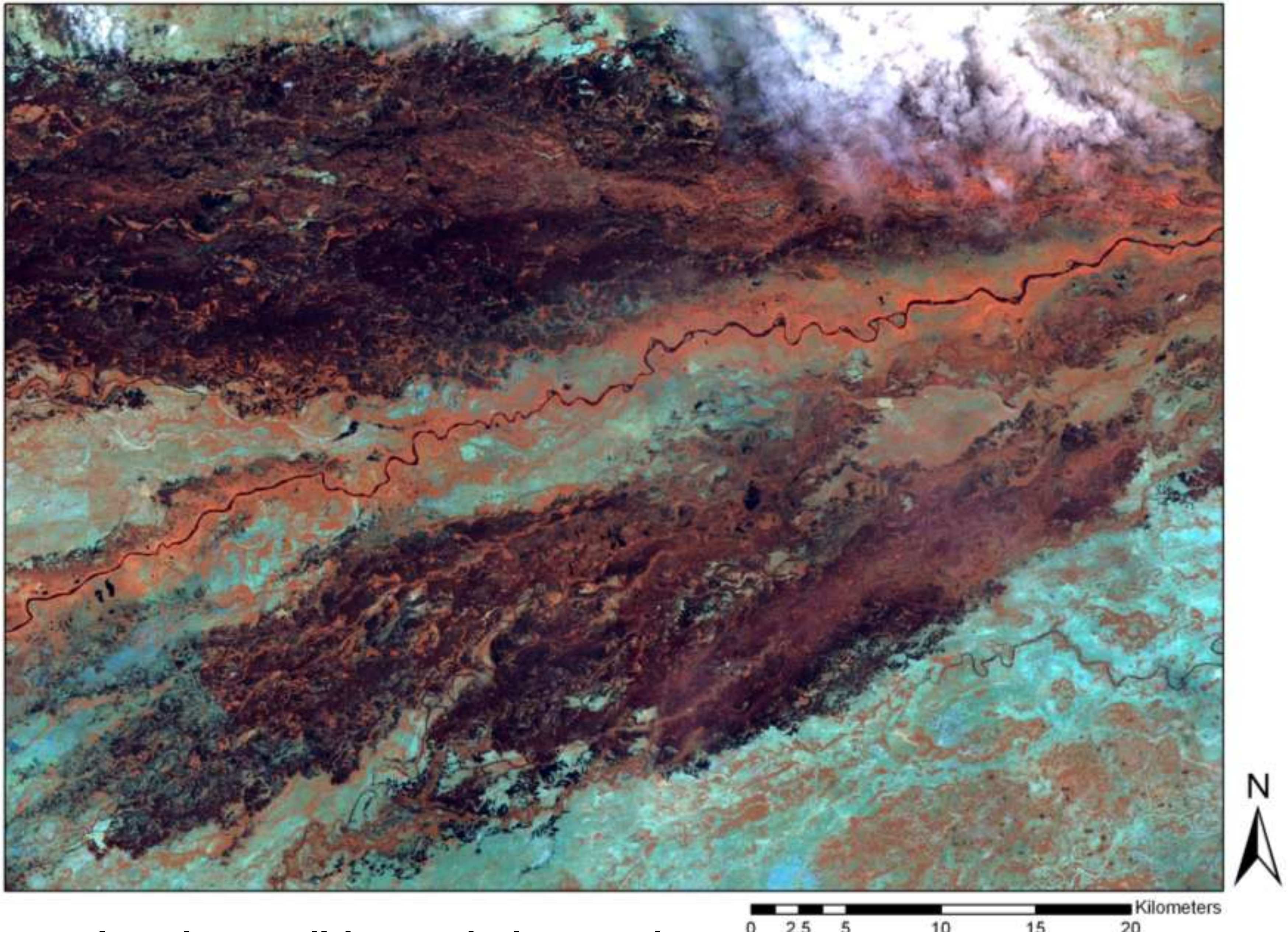
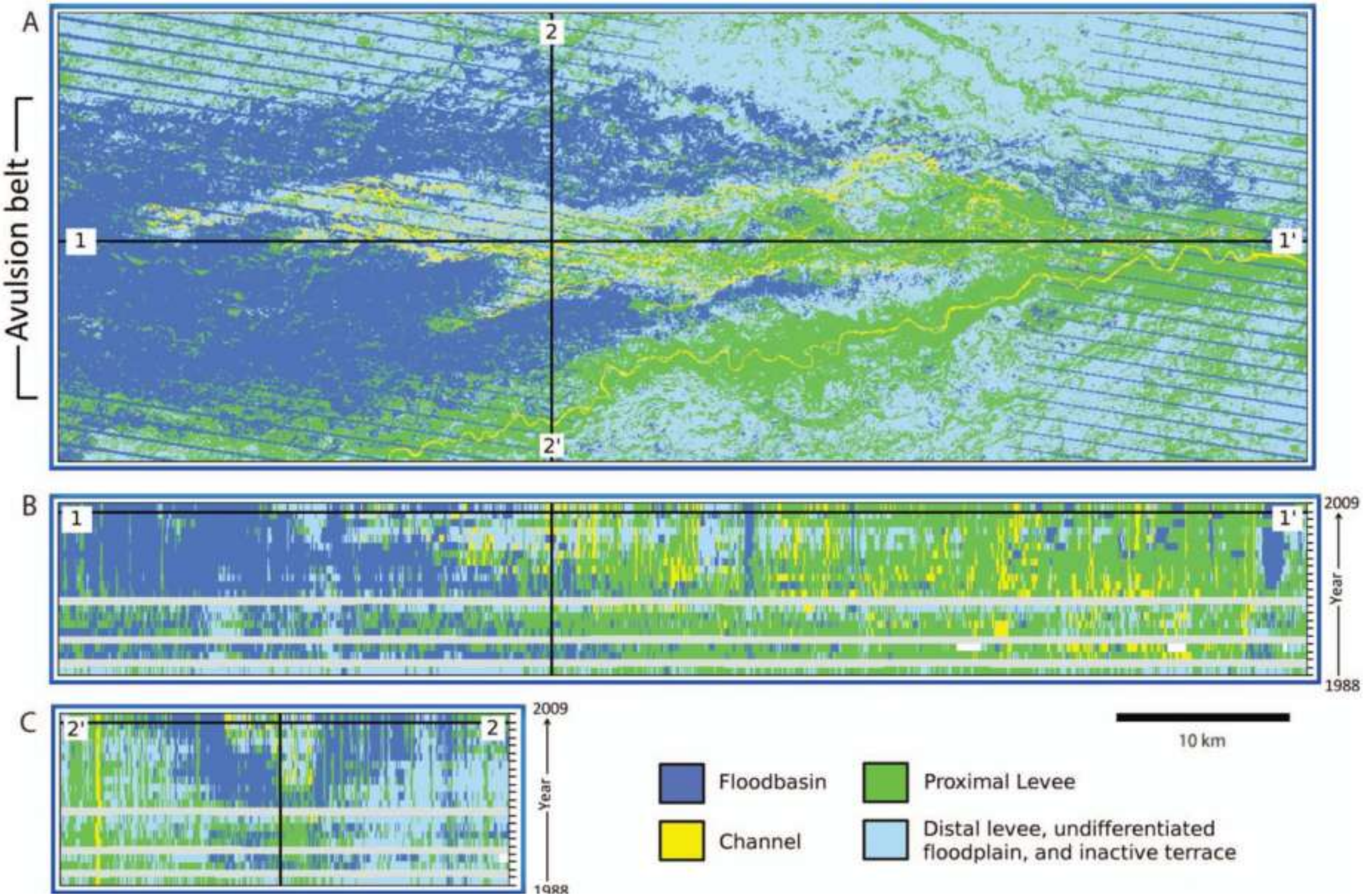


Pantanal Basin, Brazil (Taquari River DFS)

Buehler et al *2011 (movies on YouTube)*



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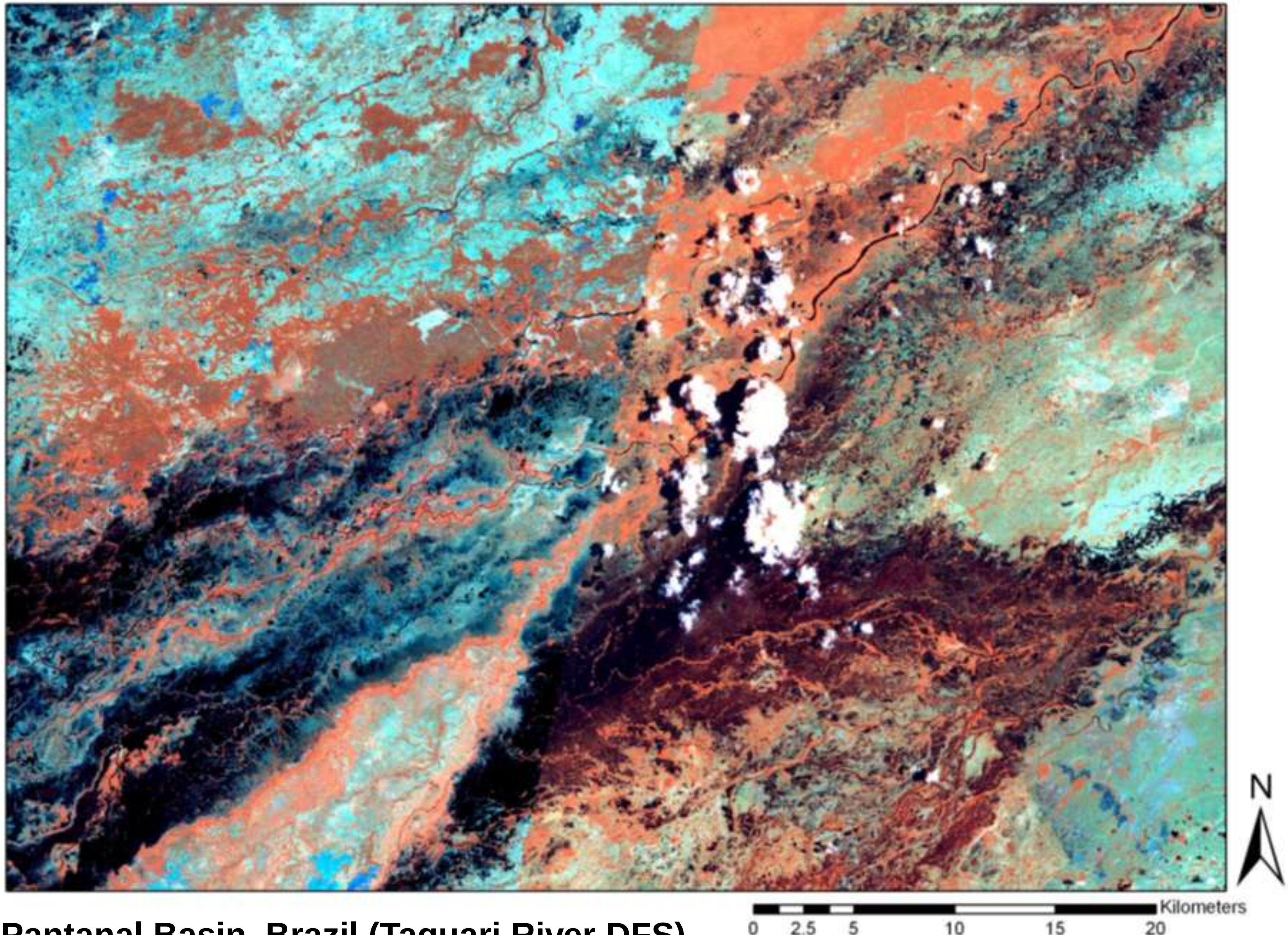

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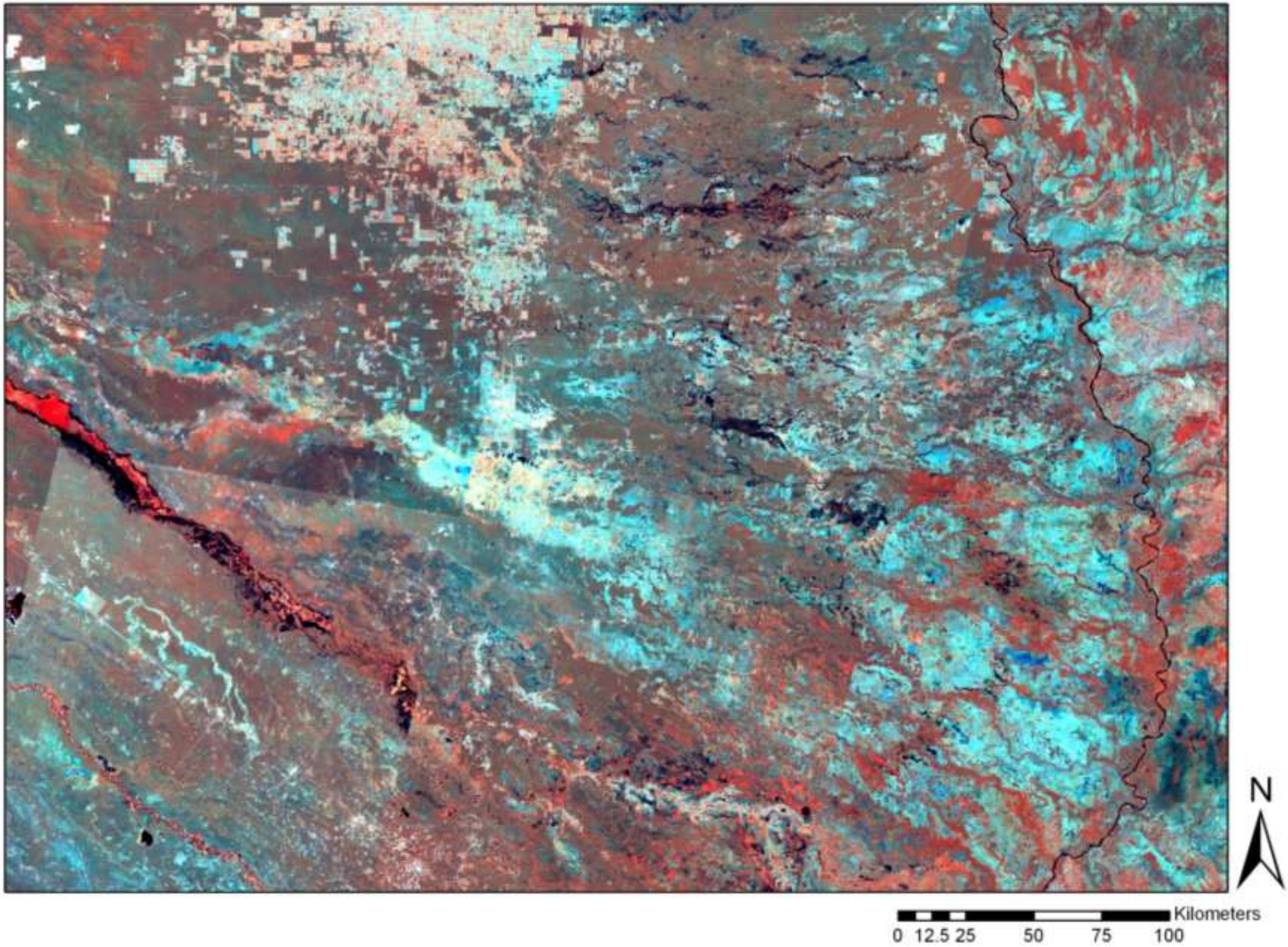
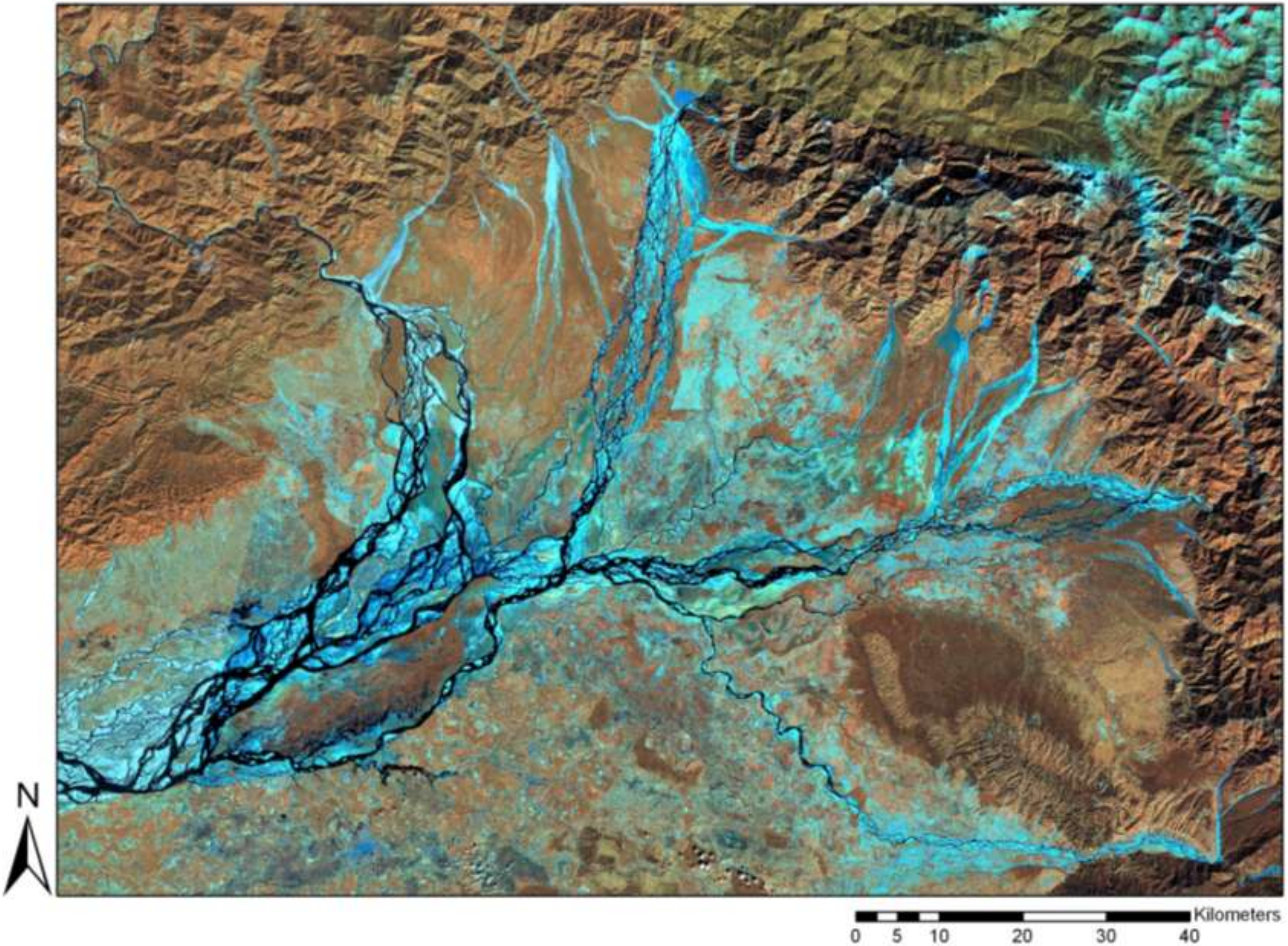
Distal Pilcomayo DFS, Argentina, Bolivia, Paraguay



Floodplain preservation along braided rivers



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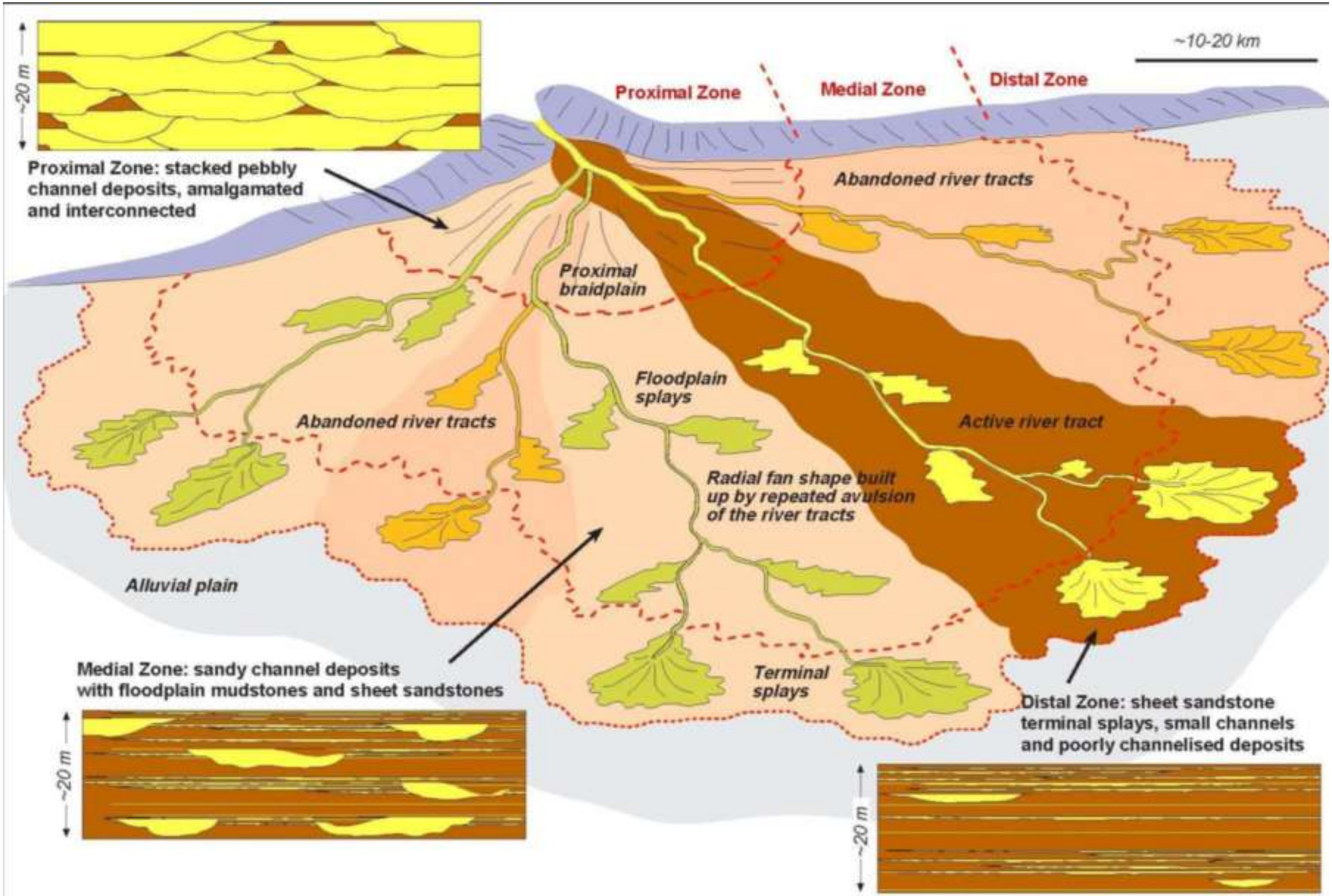
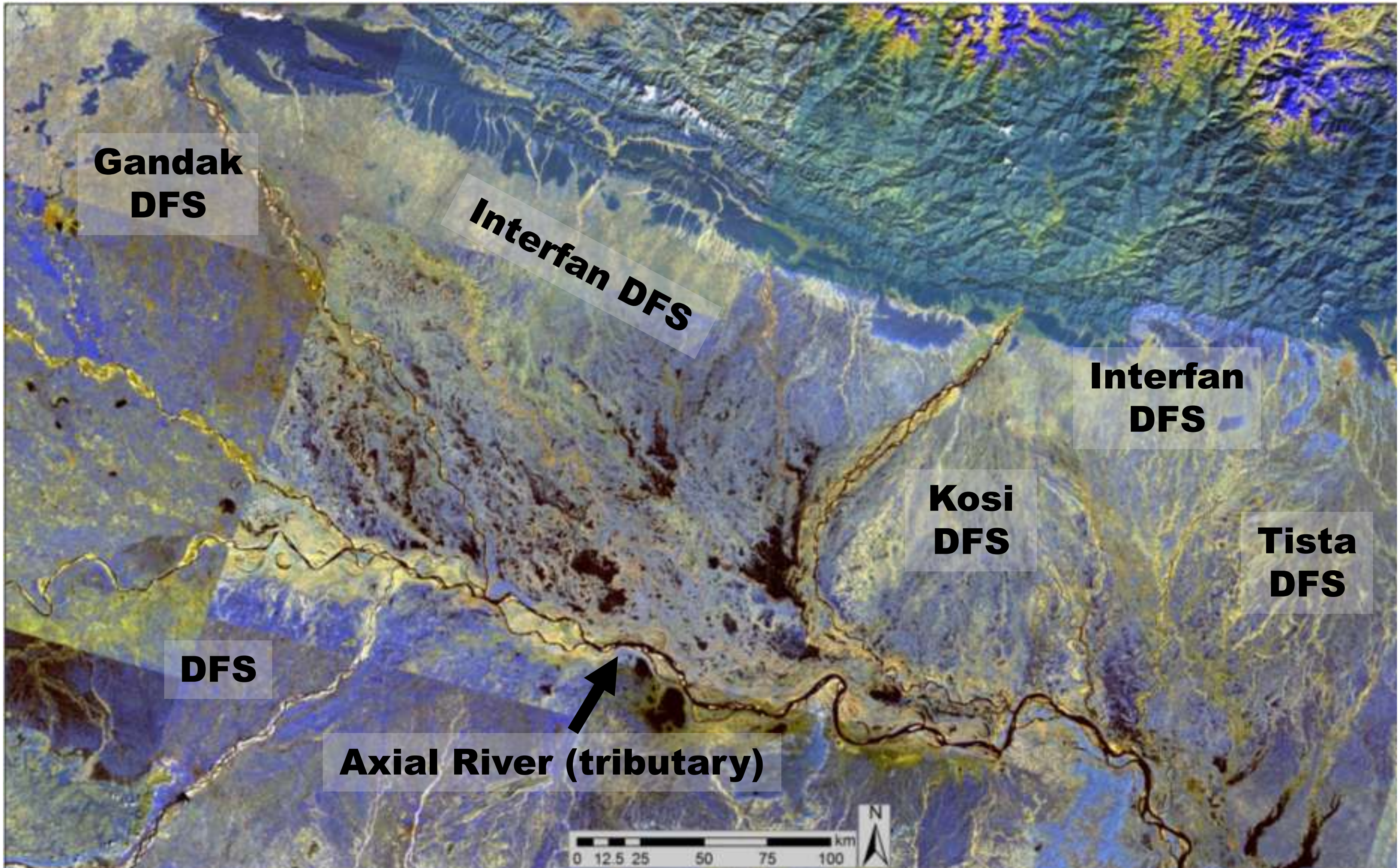
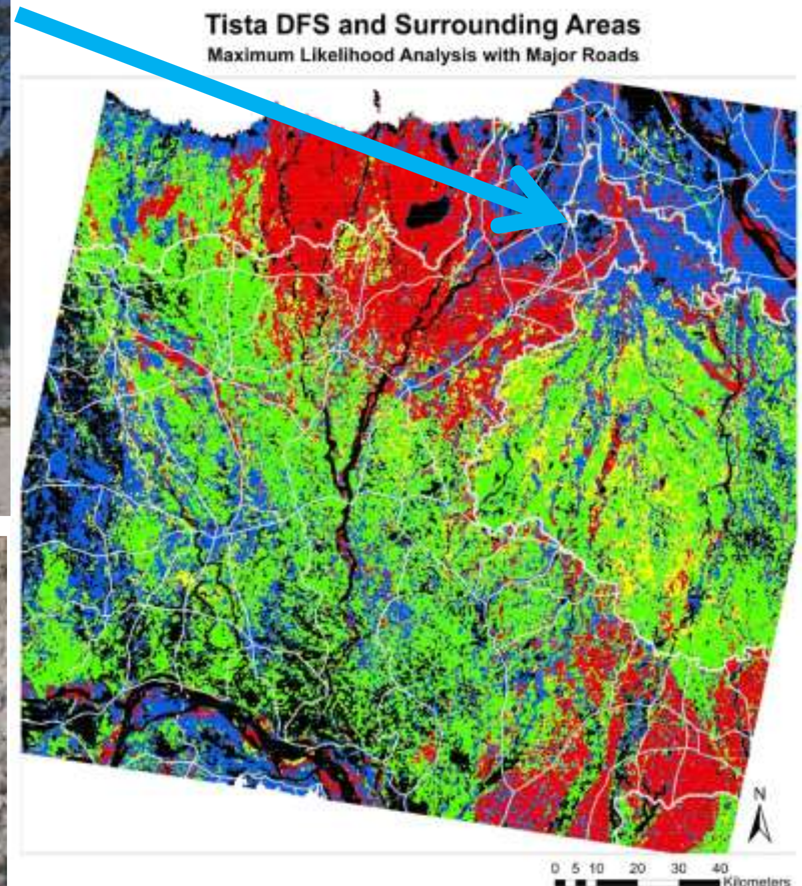


Nichols and Fisher (2007)

Himalayan Foreland Basin Variability

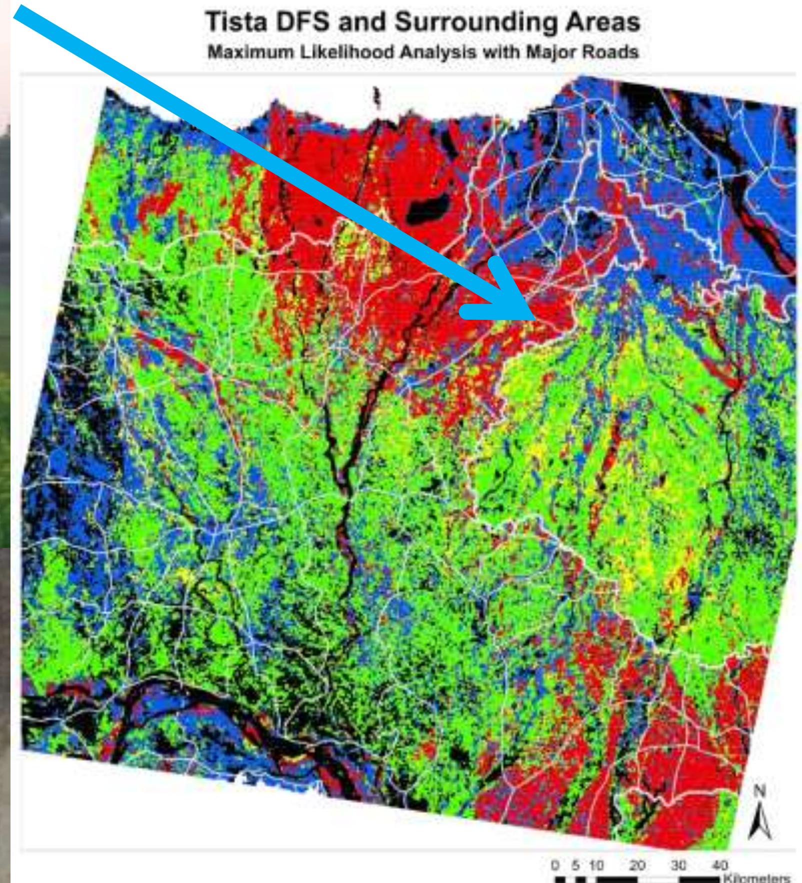
Tista / Kosi Field Evaluation





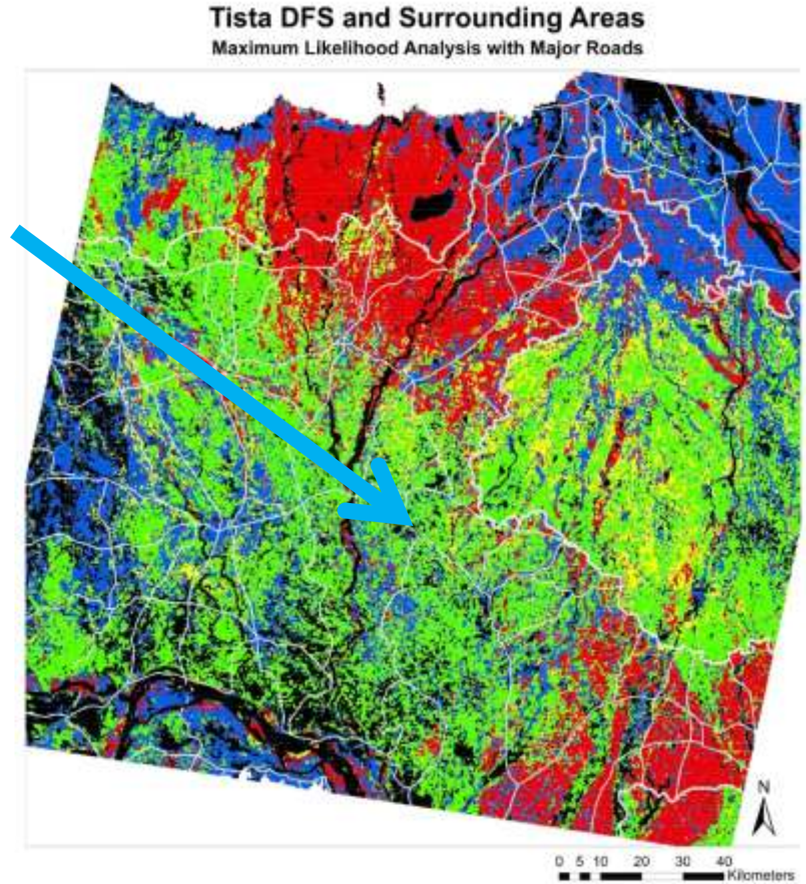
Medial Tista DFS.

- Sandy (medium).
- Low angle cross beds dominate succession, some trough fill.
- Well drained soils cap succession



Medial Tista DFS.

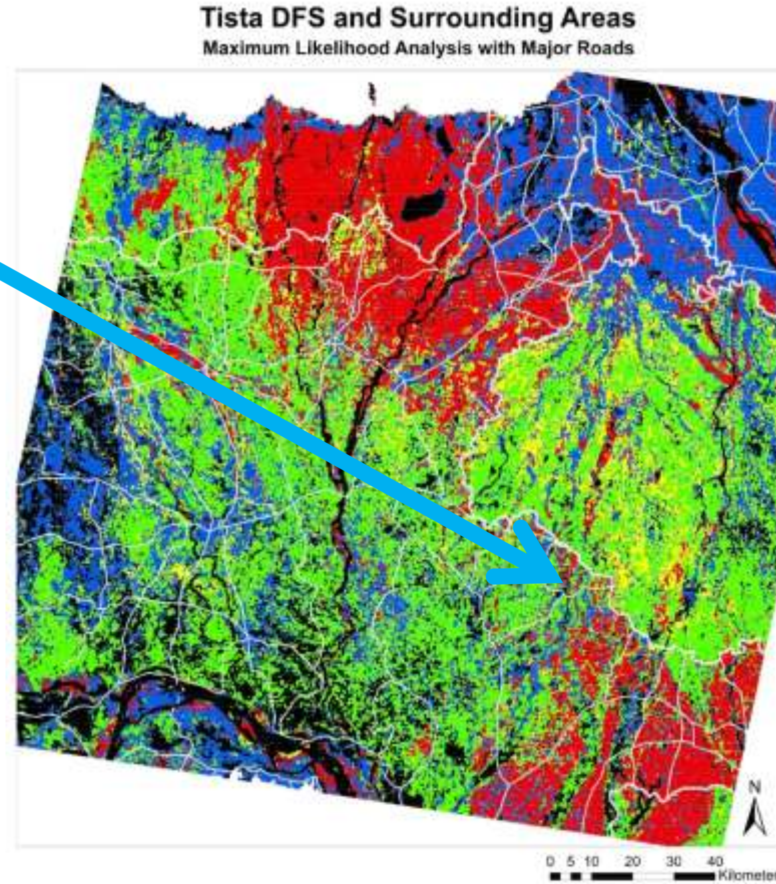
- Sandy (medium).
- Low angle cross beds dominate succession, some trough fill.
- Well drained, thick soil caps succession.



Medial/distal Tista DFS.

- Sandy and silty (fine-medium).
- Moderately drained soil caps succession.
- Mottling common, indicating wetting and drying cycles.


Chartwell

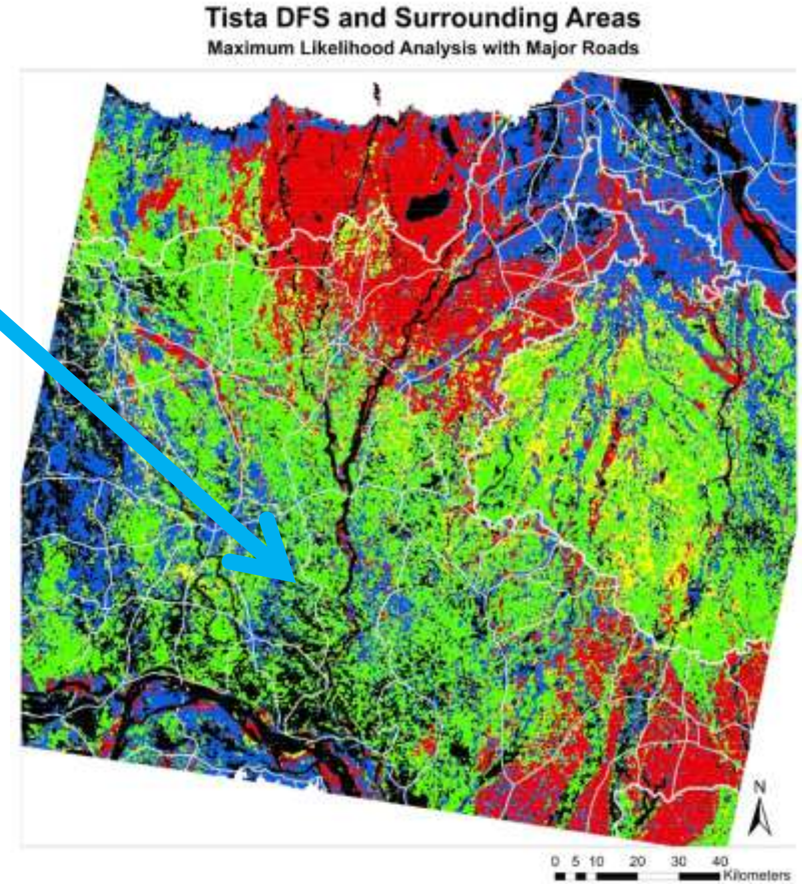


Distal Tista DFS.

- Silty and clay-rich.
- Sandy channels (medium sand)
- Moderately drained soils. Mottled, but generally gray color.


Nikon


Nikon

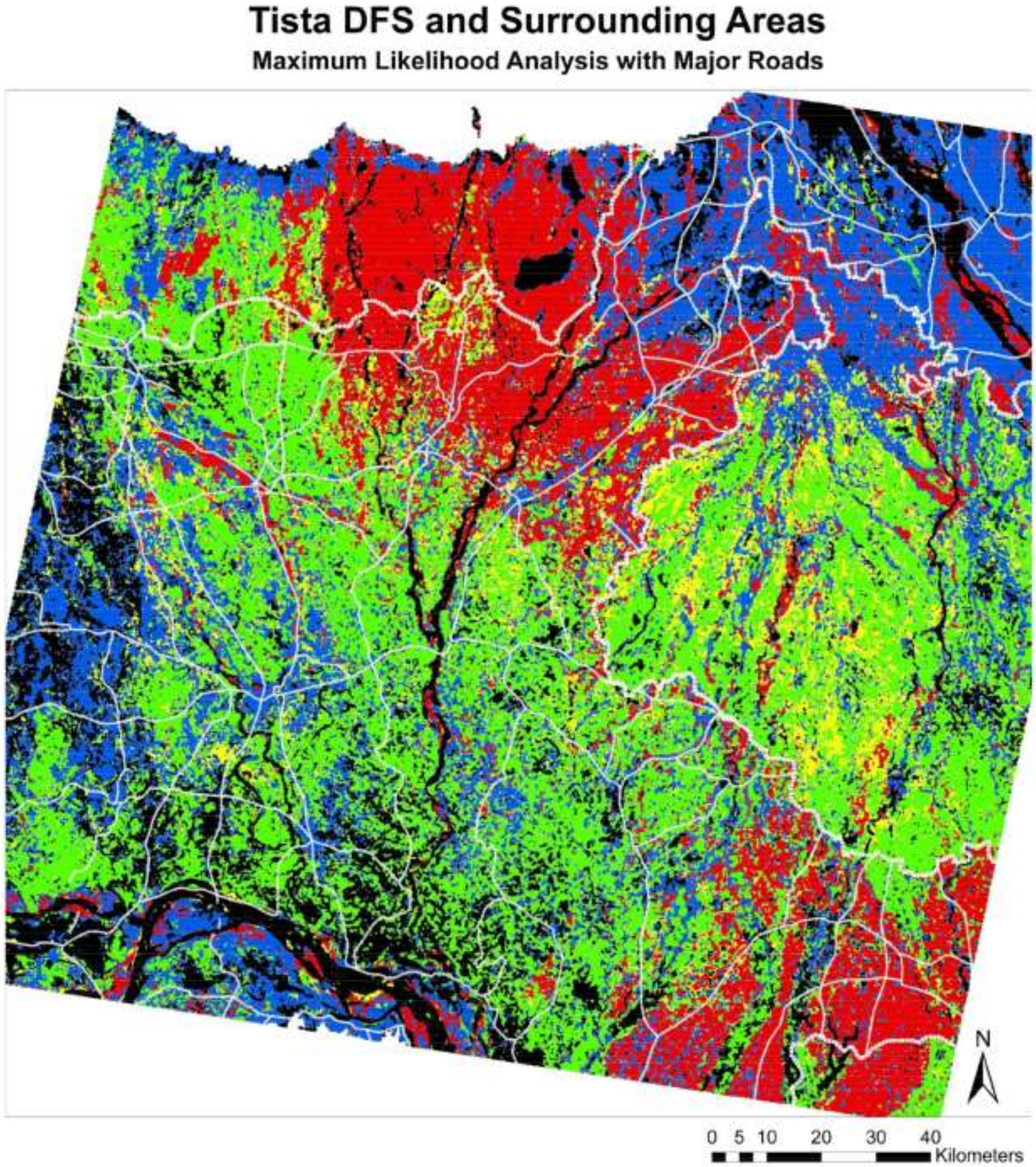


Distal Kosi DFS

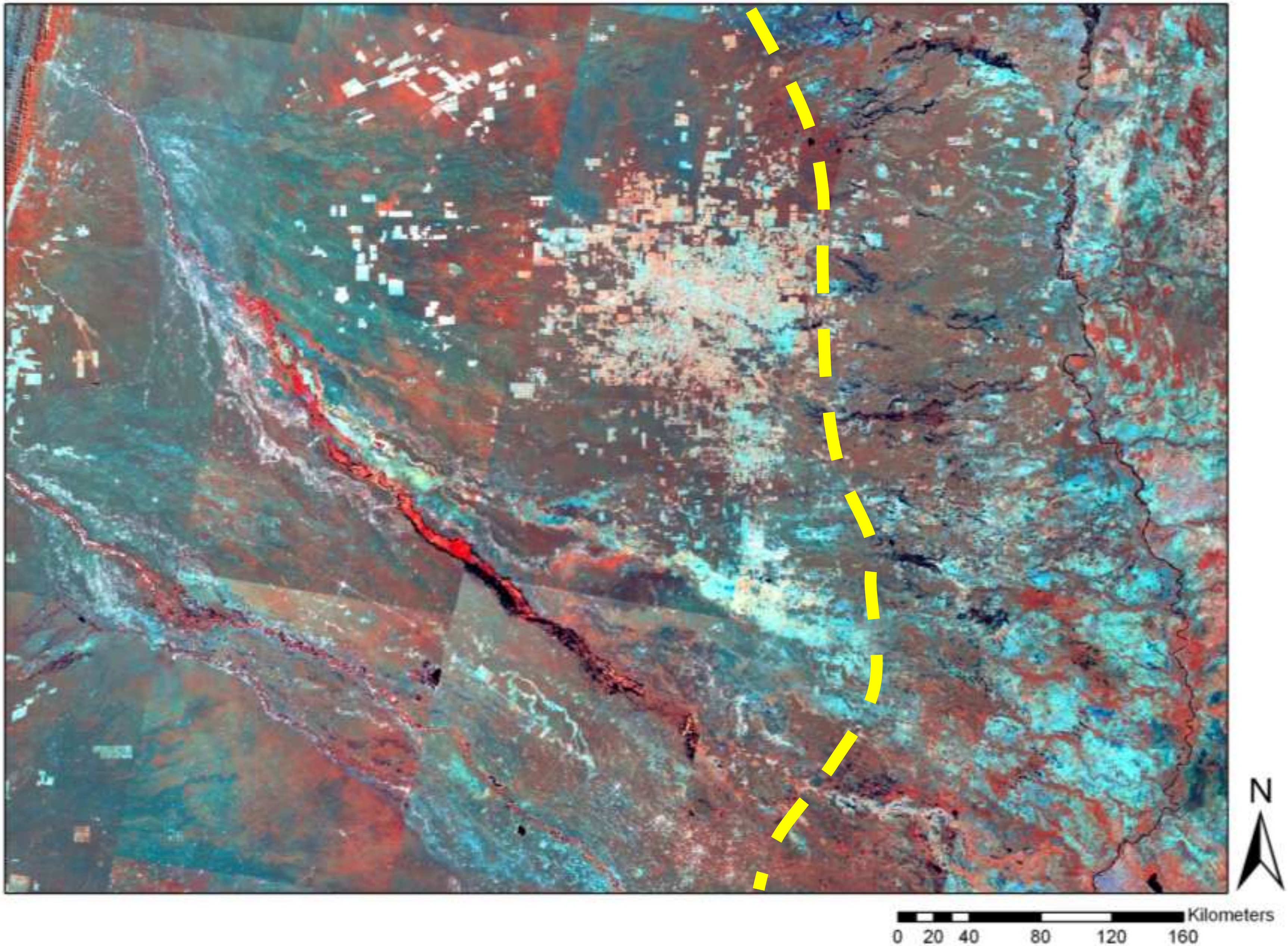
- Poorly drained soils – water table lies 1-2 m below surface, depending on time of year.
- Clay-rich, mottled, root halos, crawfish burrows


Analysis on Tista DFS Imagery

- Shows indications of soil moisture
- Gleyed soils more common distally; well-drained soils more common near apex areas

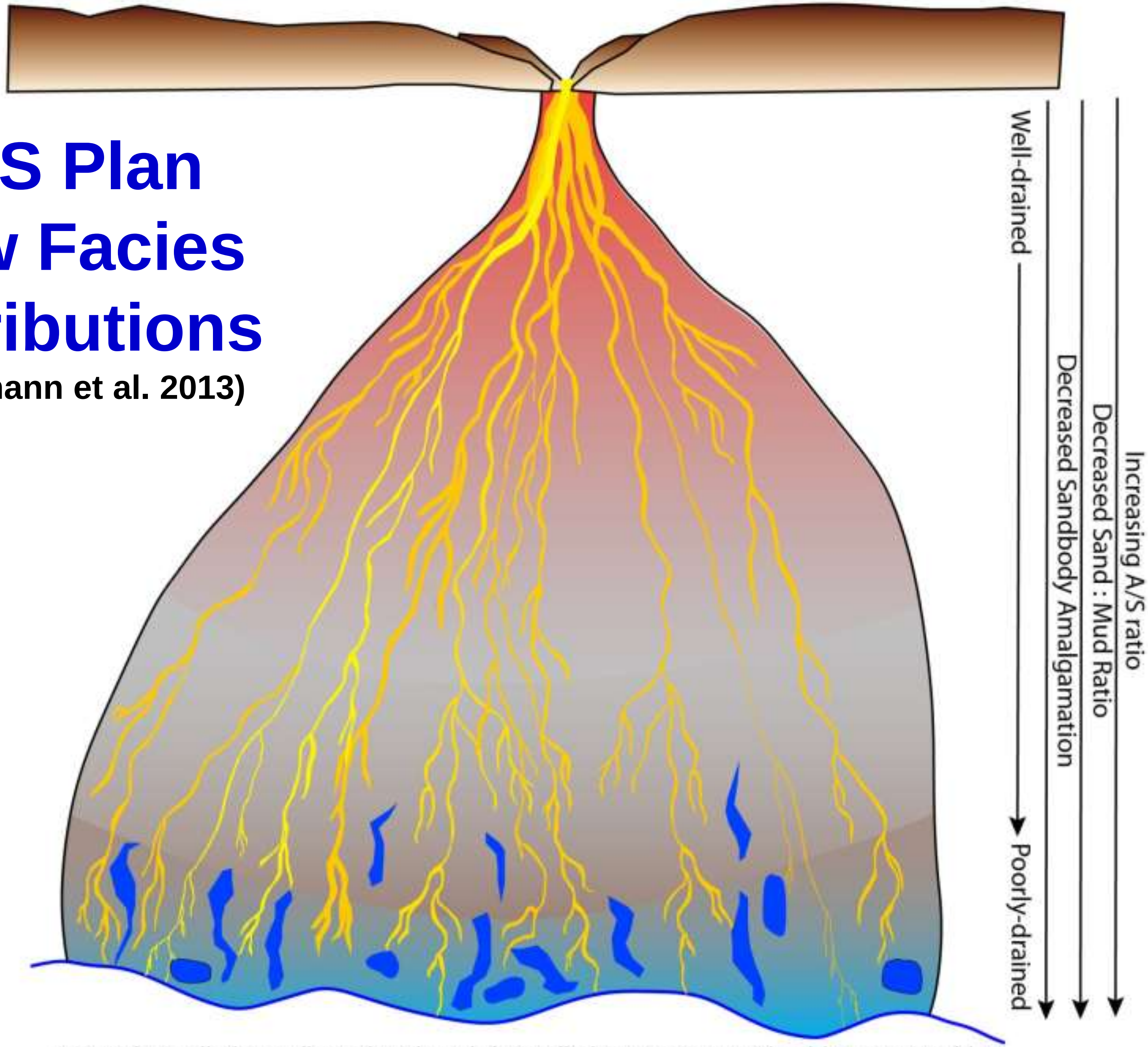


Pilcomayo DFS, Argentina, Bolivia, Paraguay



DFS Plan View Facies Distributions

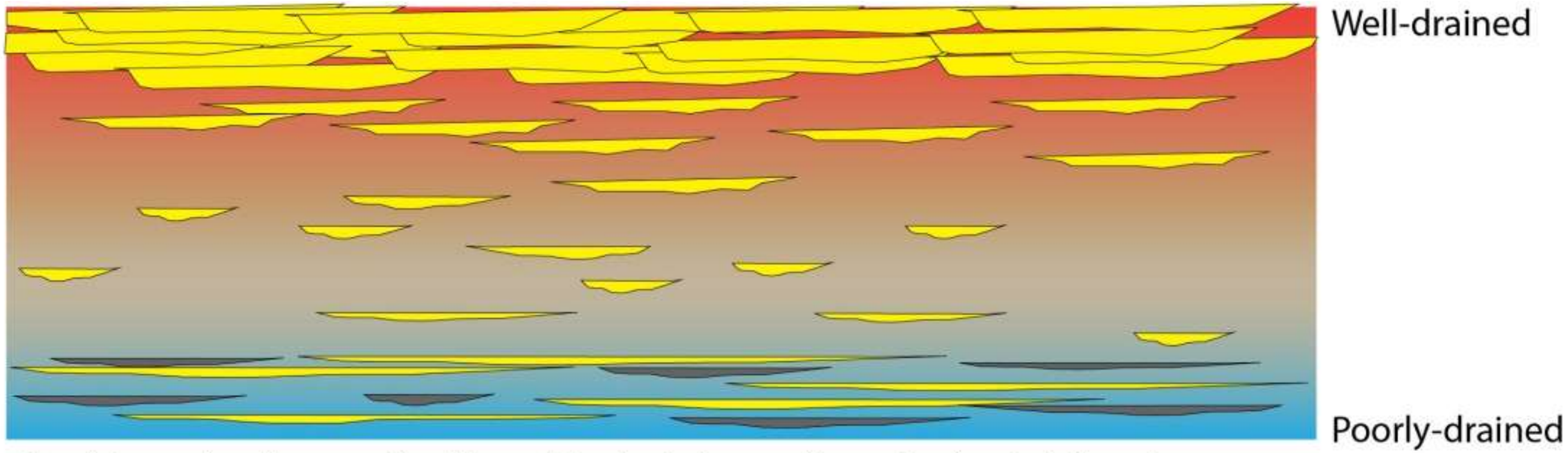
(Weissmann et al. 2013)



Active channelbelt in yellow; abandoned channelbelts in orange; wetland/lacustrine in blue.

Schematic Vertical Section from DFS Progradation

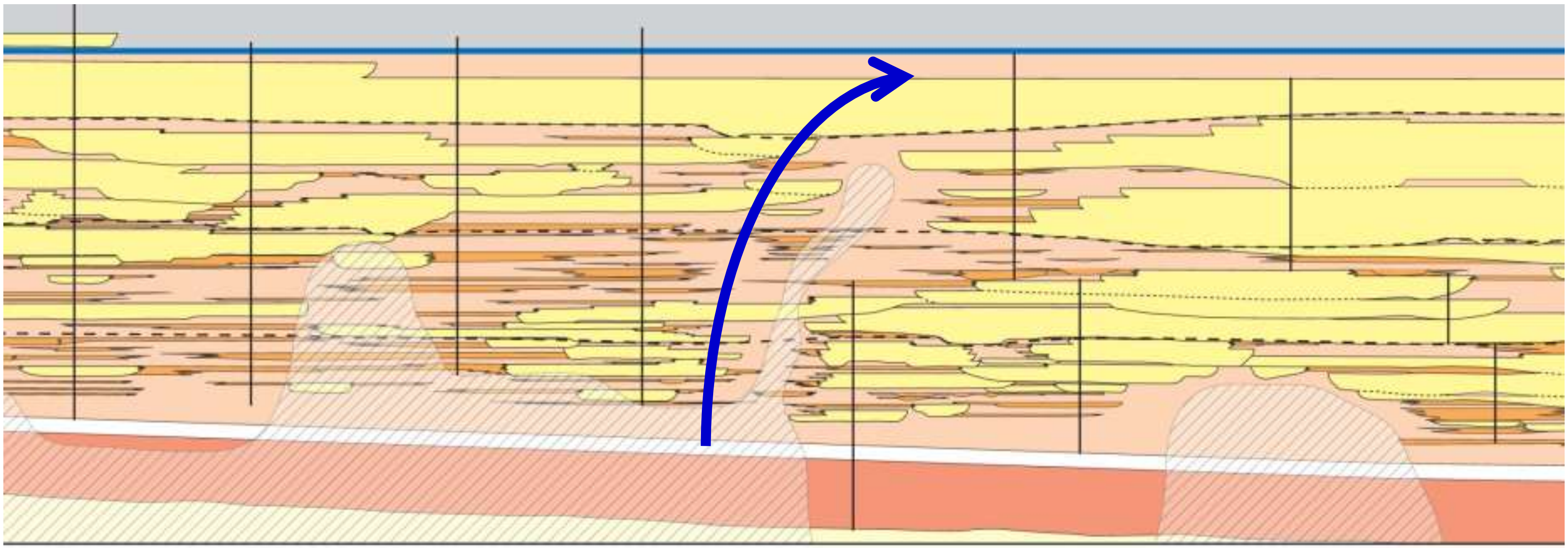
(Weissmann et al. 2013)



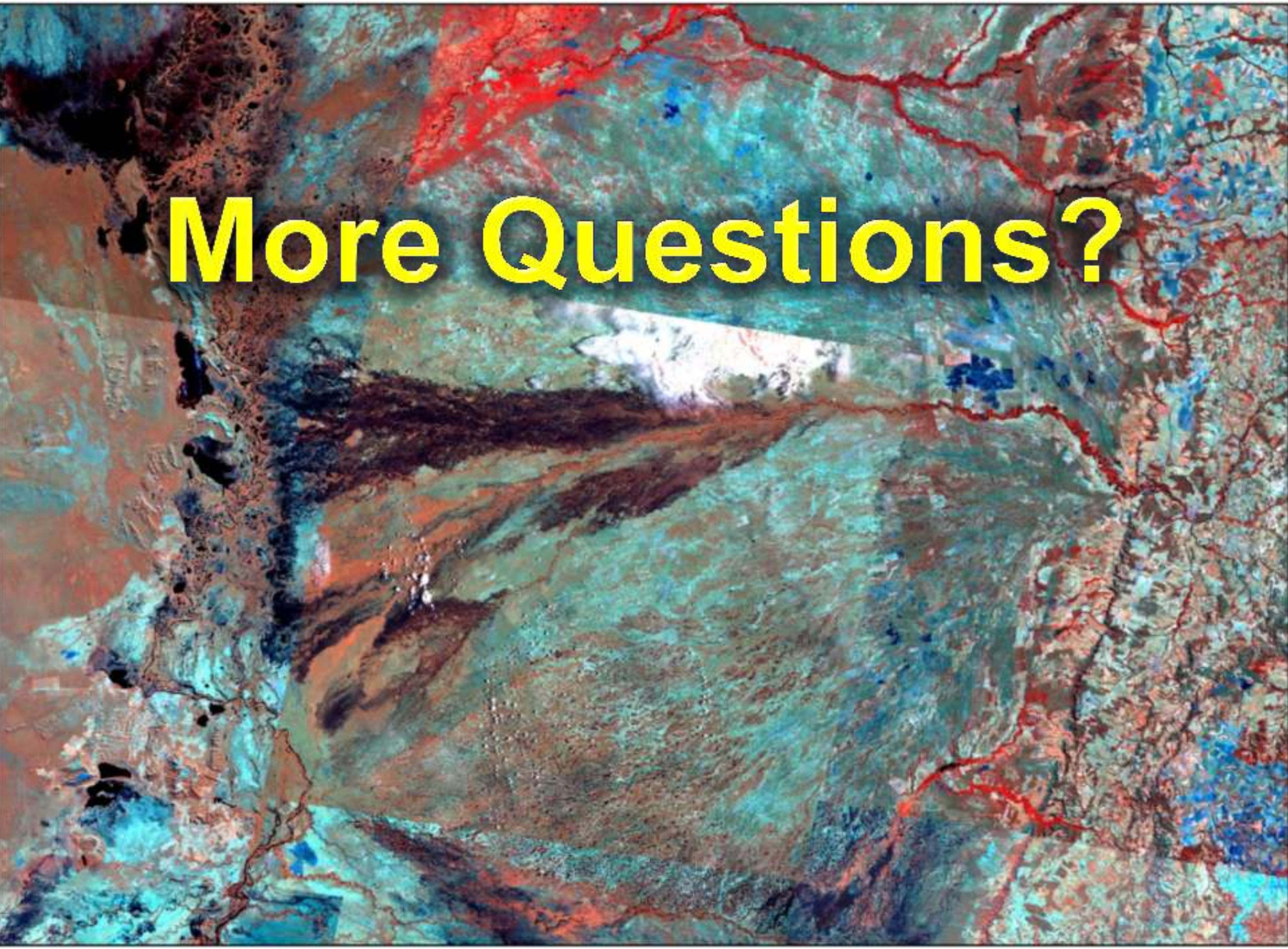
Sandstones in yellow; wetland/lacustrine in dark gray; No vertical scale inferred.

Possible Progradational Succession

Morrison Formation, Utah

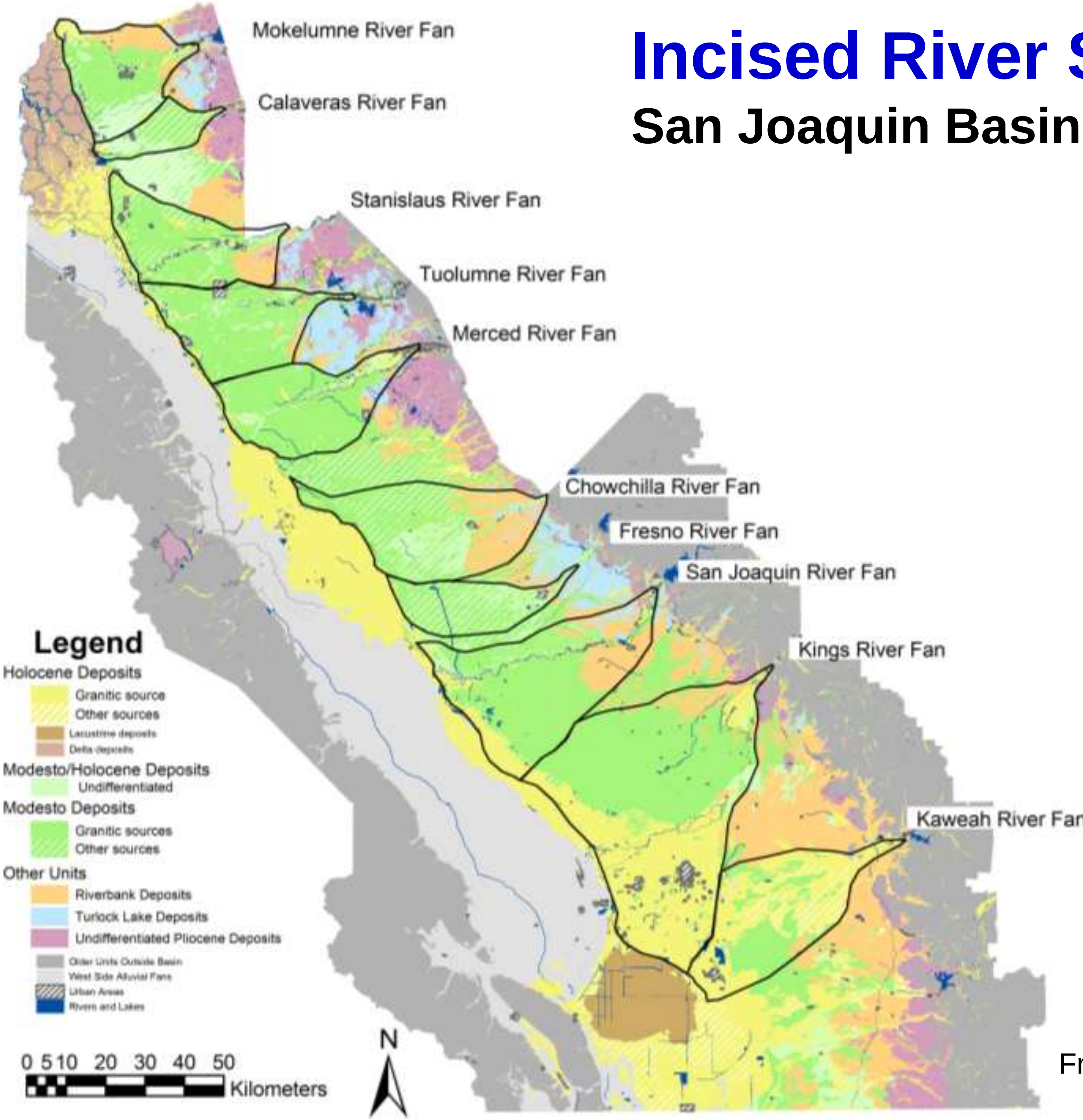


From Kjemperud et al 2008


More Questions?

Incised River Systems

San Joaquin Basin, California

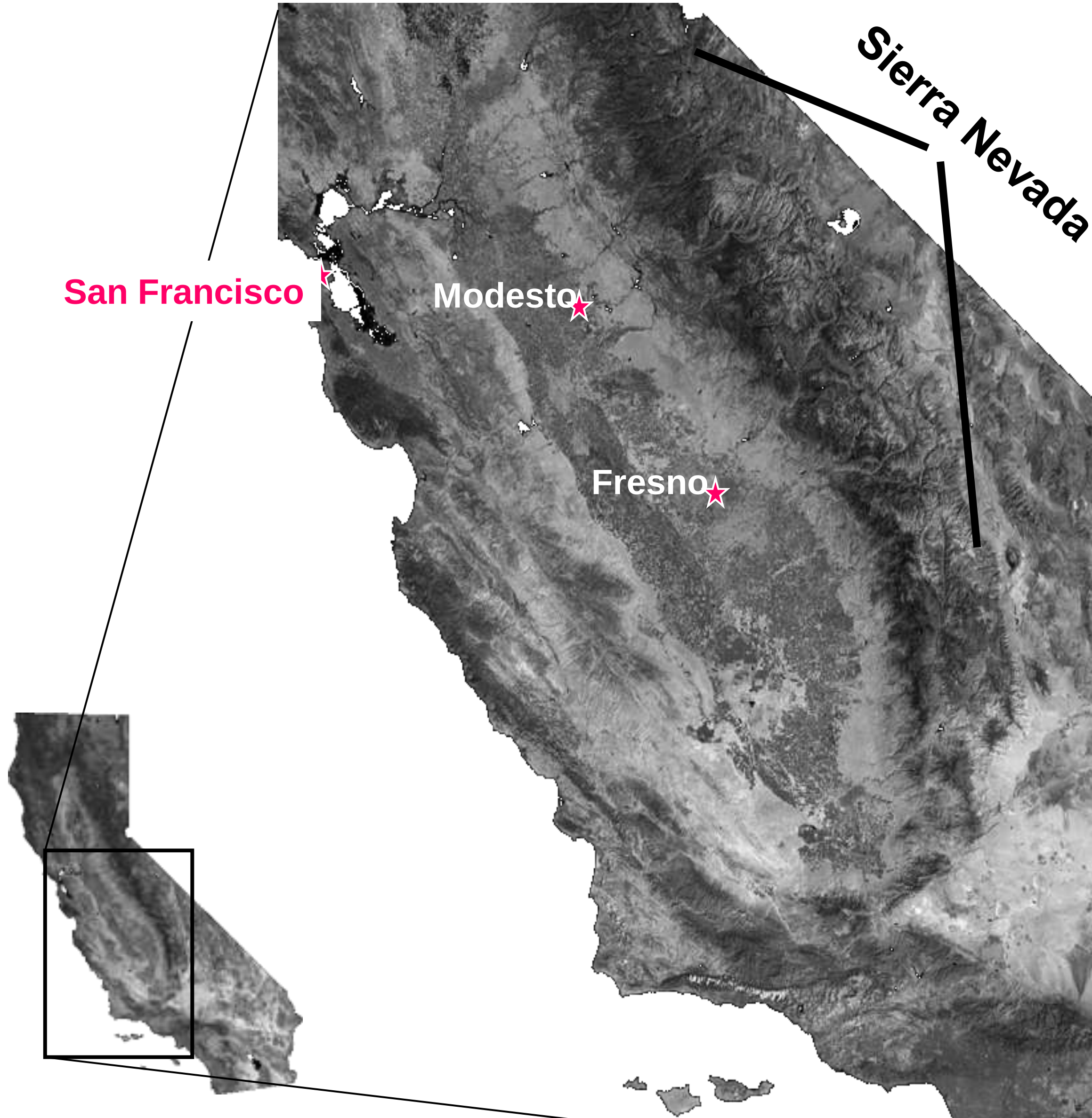


From Weissmann et al *2005*

San Joaquin Basin

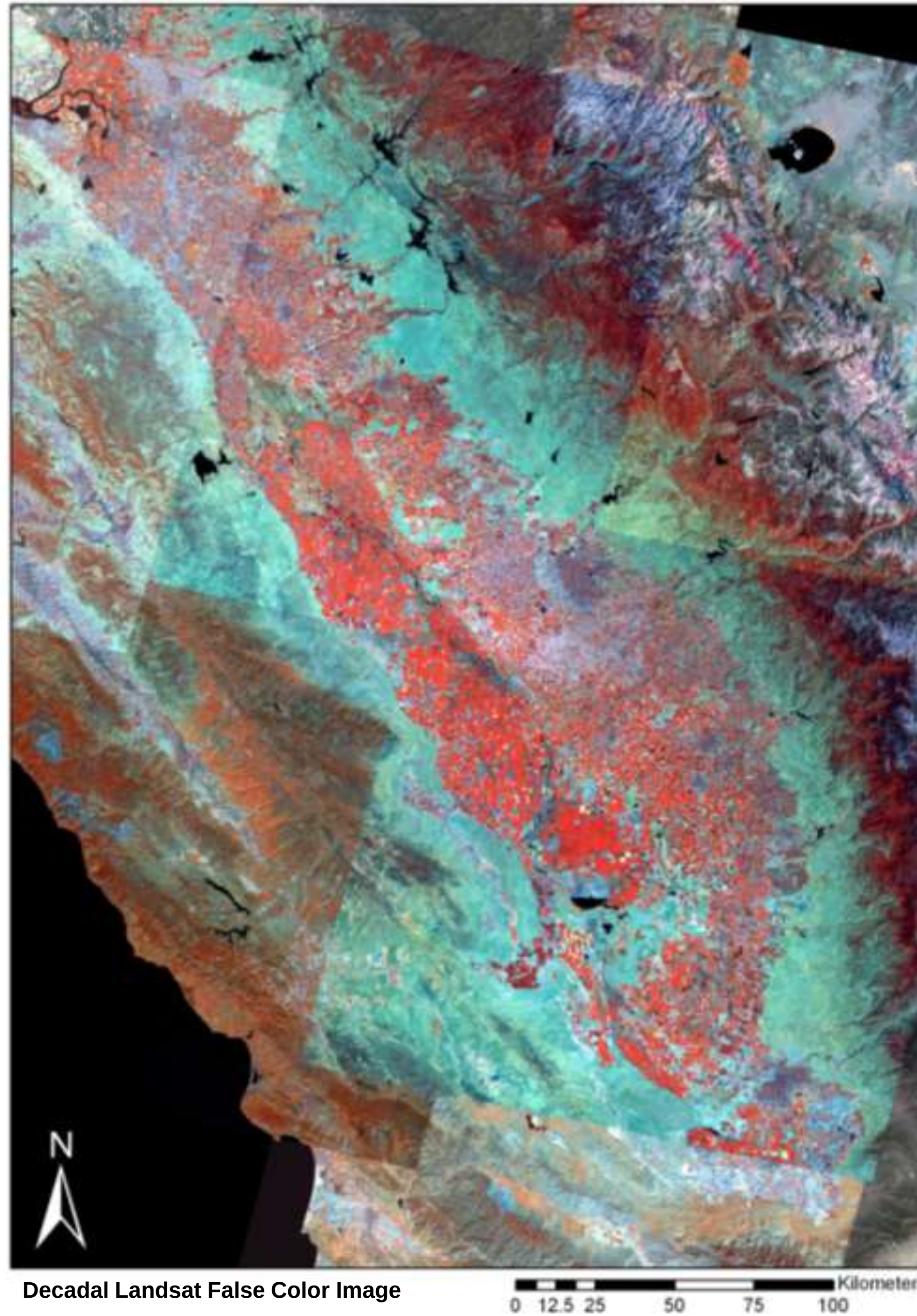
Outline

- **Motivation**
- **Controls on Stratigraphic Evolution**
  - **Sequence Development**
  - **Incised valley fills**
- **Examples and Hydrogeologic Implications**
  - **Kings River Fan**
  - **Tuolumne River Fan**
  - **Chowchilla River Fan**



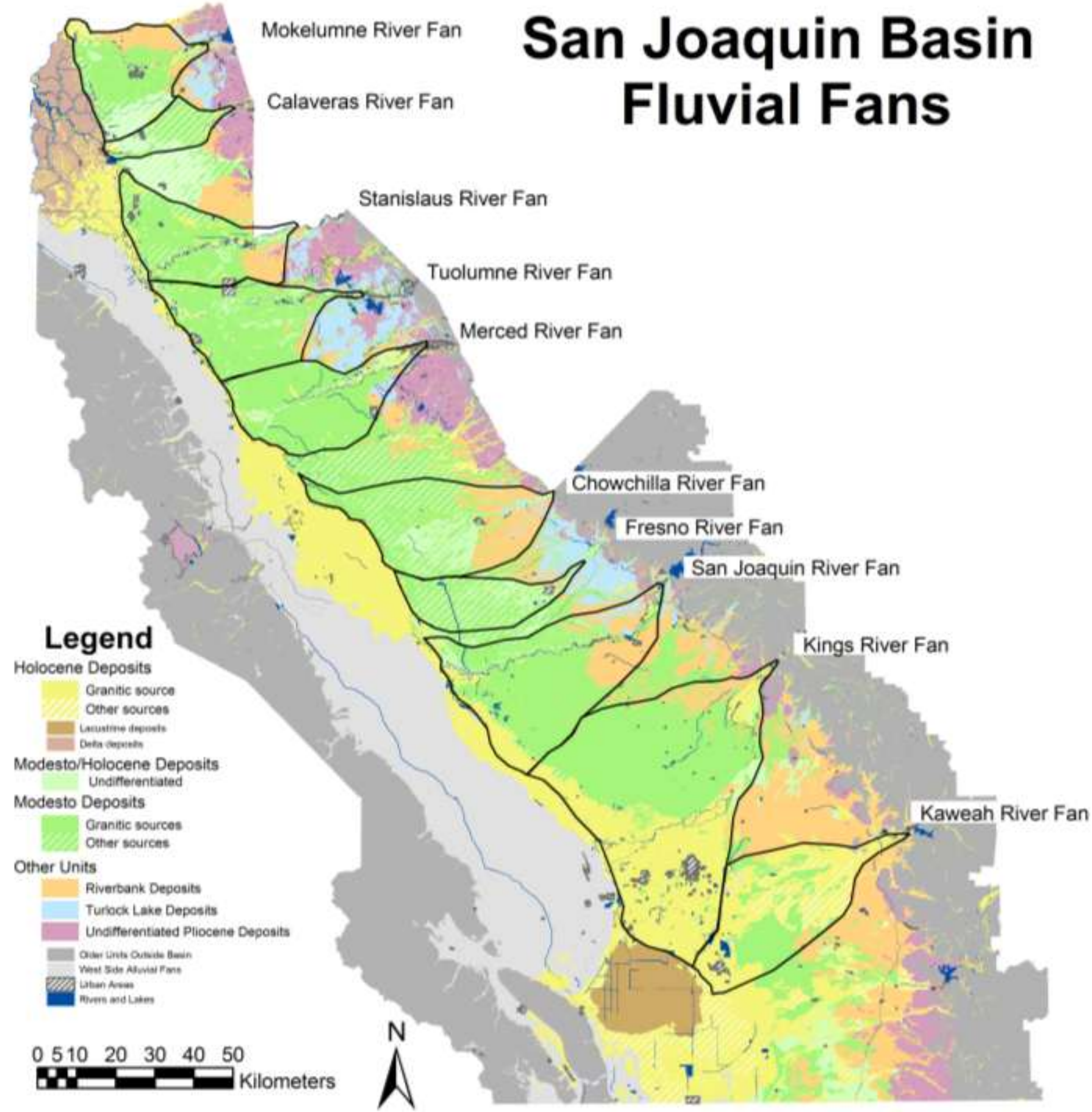
Motivation

- **California basins excellent models of modern basin depositional systems.**
  - Well studied, a lot of data.
- **Growing population**
  - Increased demand on water resources
  - High potential for contamination (industrial, agricultural)
- **Surface-water storage maximized**
  - No more dams
  - Where can we store water?
- **Heterogeneity and stratigraphy often missing from groundwater studies!**



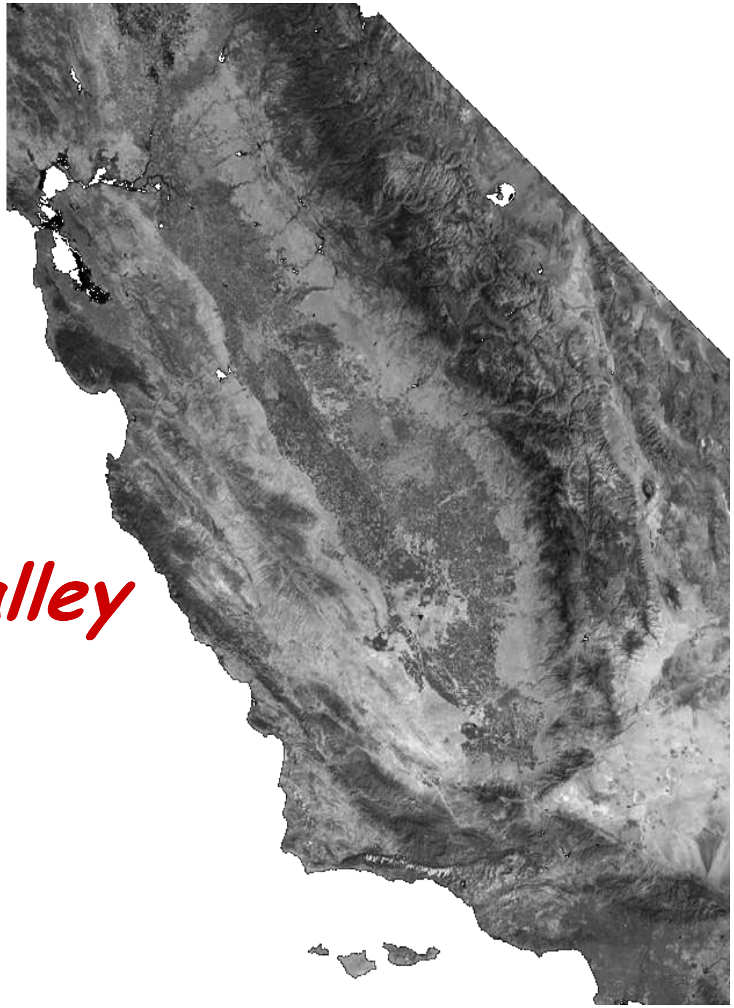
Decadal Landsat False Color Image

San Joaquin Basin Fluvial Fans



Controls on Stratigraphic Architecture

- ratio of sediment supply to stream discharge
- basin subsidence rate
- local base level change
- basin width



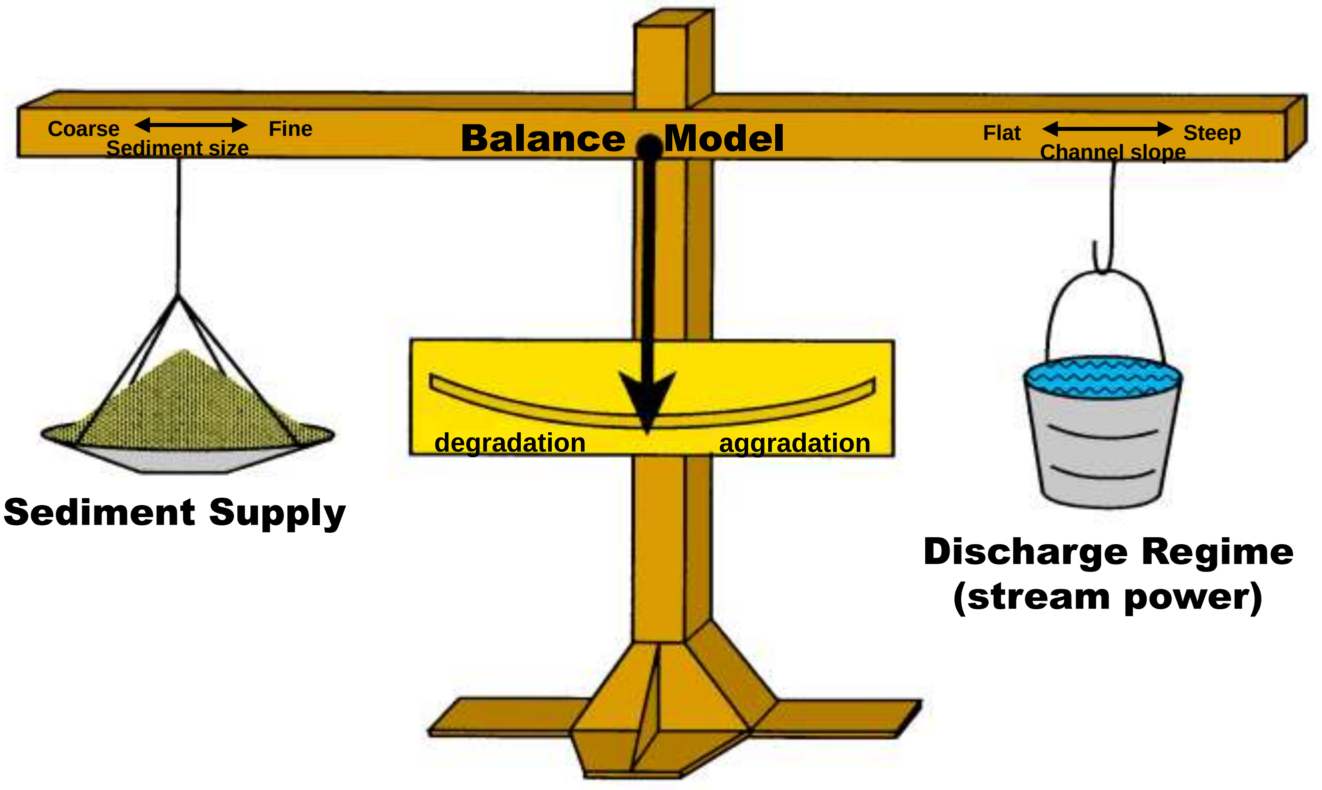
Ultimately, these control:

1. ***whether an incised valley fill exists;***
2. ***the incised valley fill geometry***

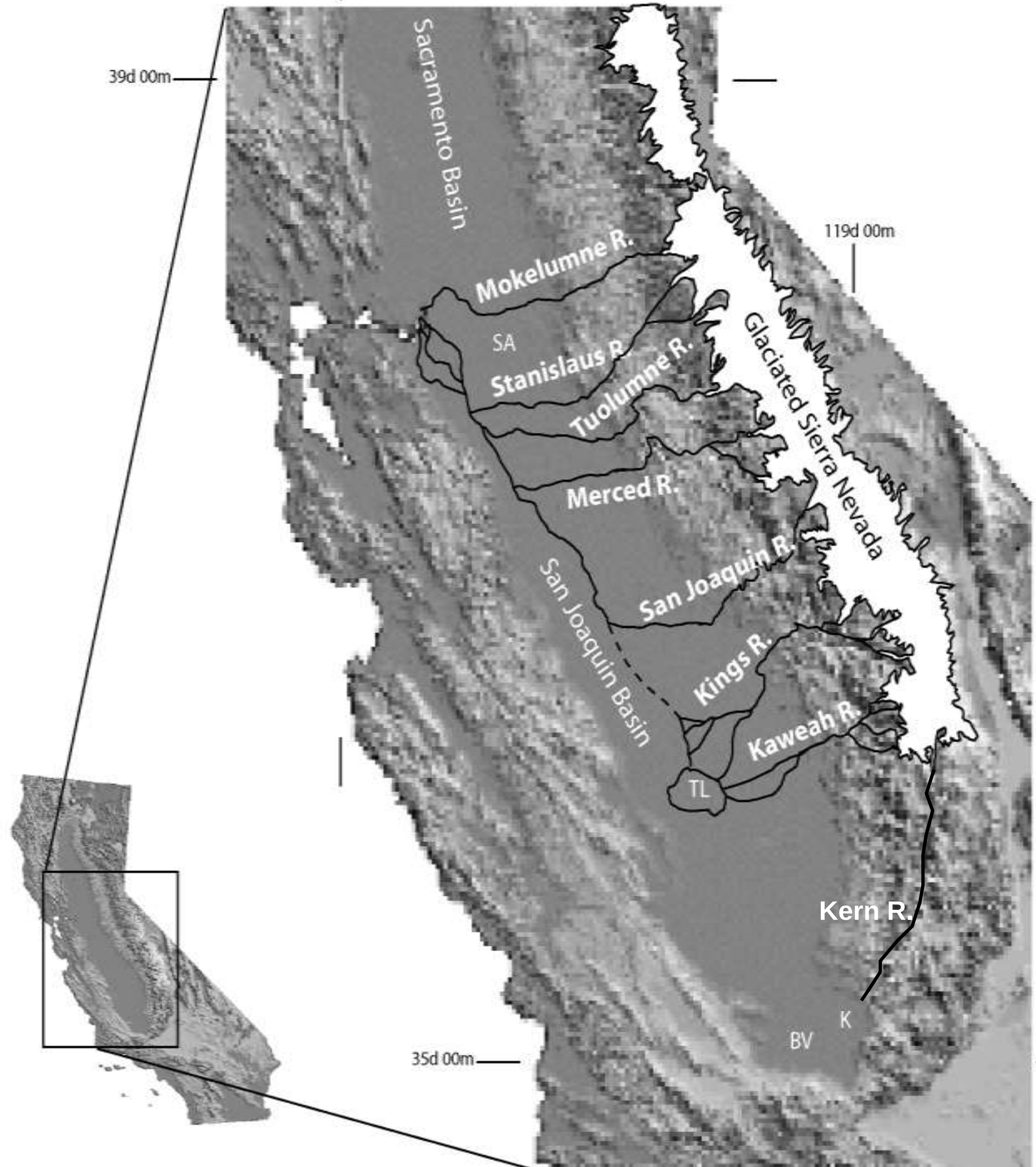
From Weissmann et al., *2005*

Controls on Stratigraphic Architecture

- **ratio of sediment supply to stream discharge**

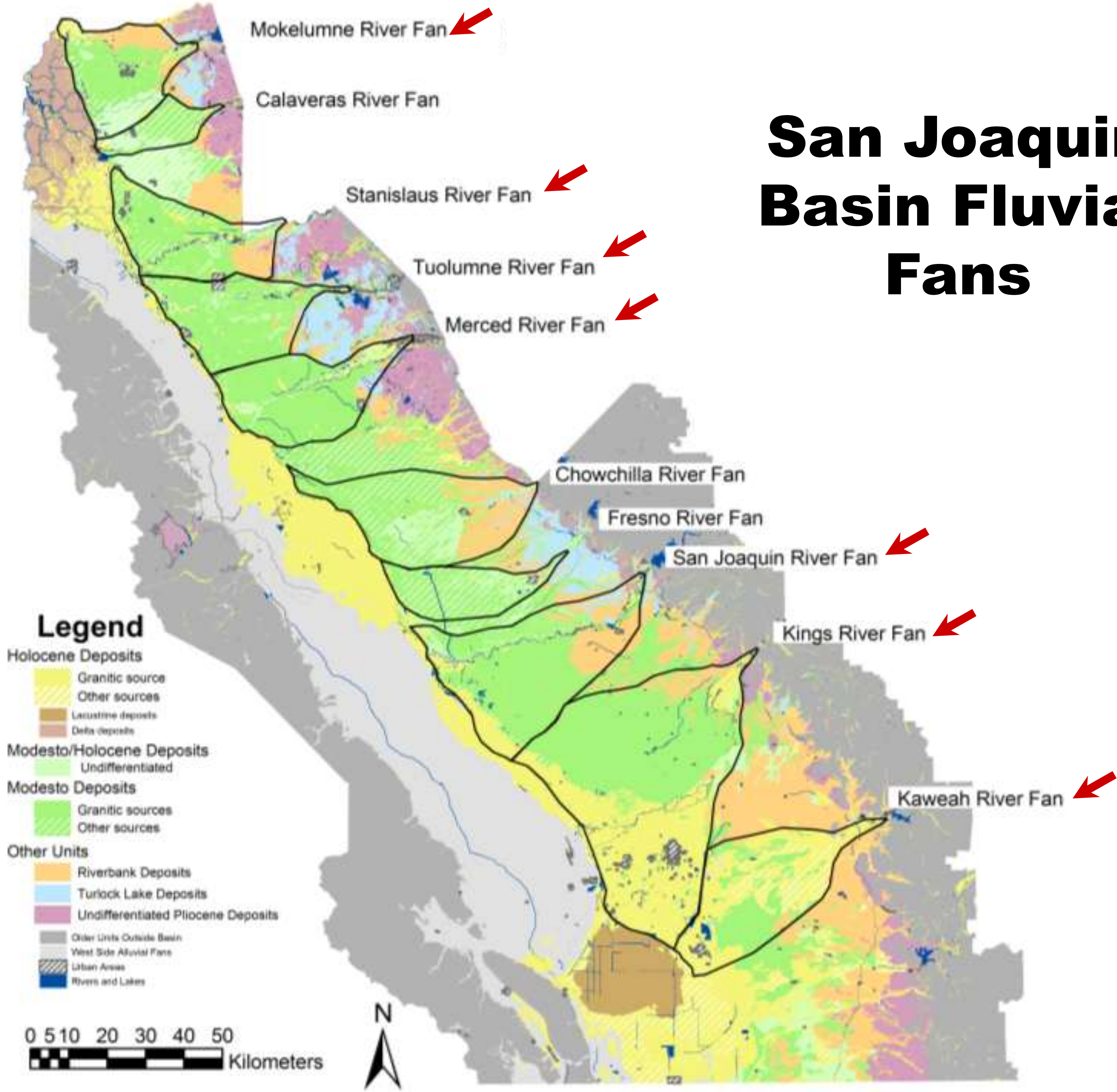


Lane 1955

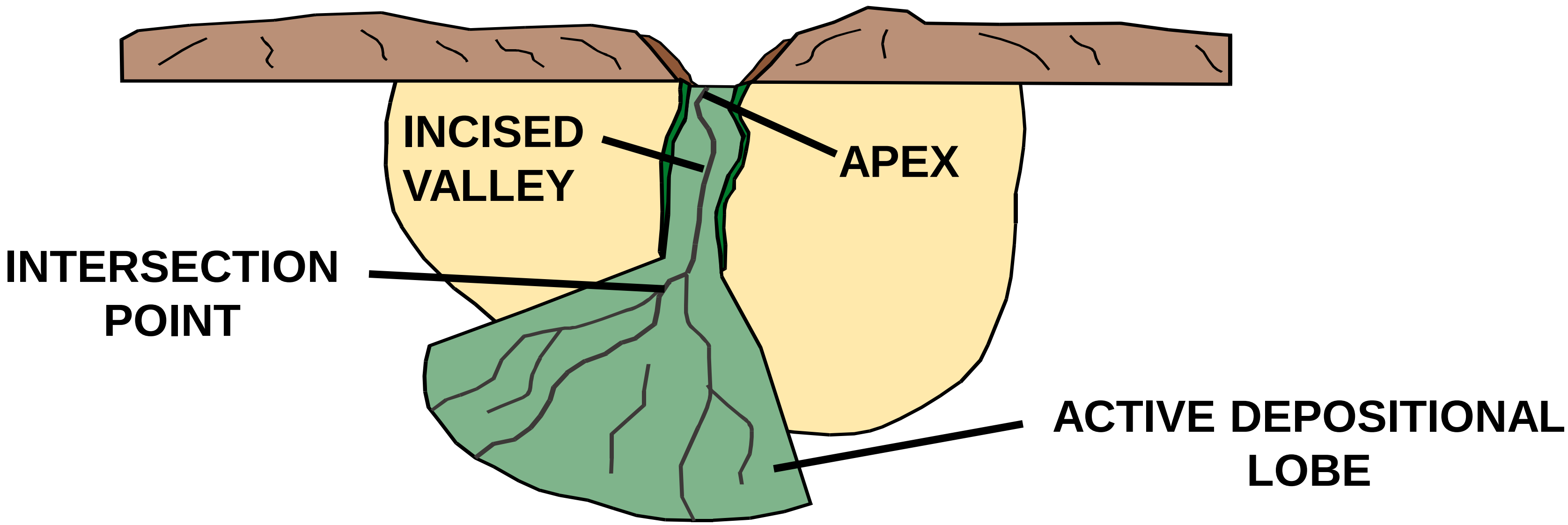


Glacial extent from Wahrhaftig and Birman, 1965

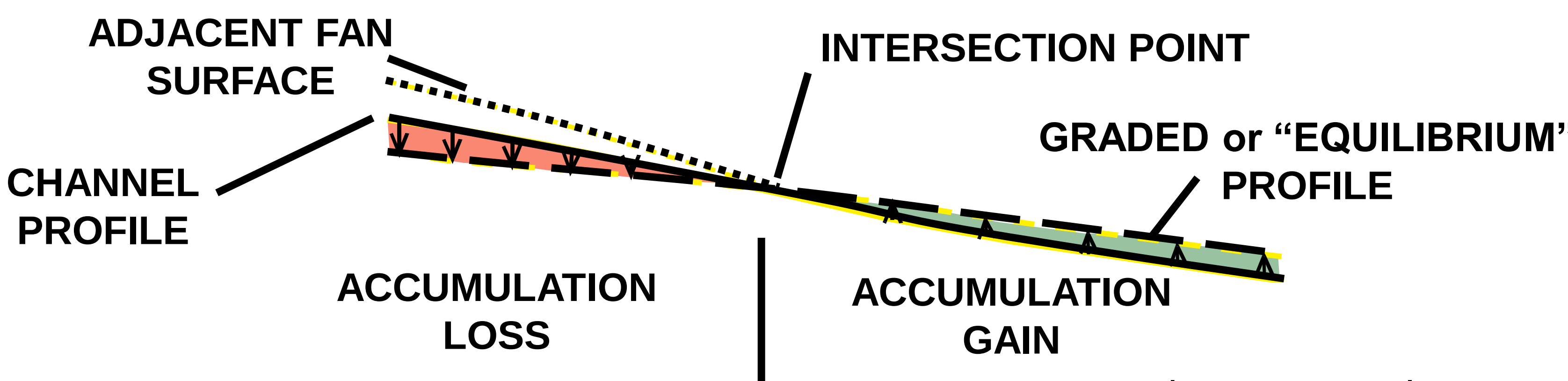
San Joaquin Basin Fluvial Fans



PLAN VIEW

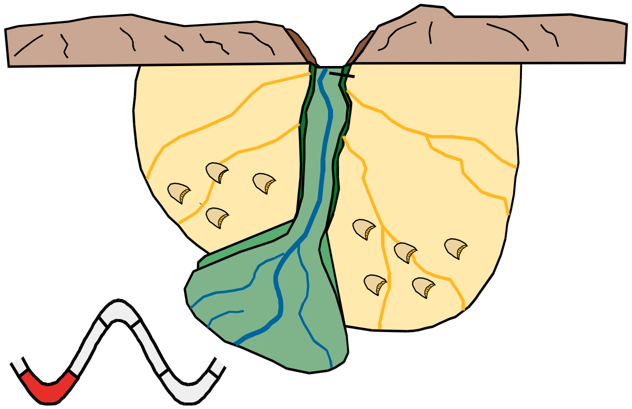


CROSS-SECTIONAL VIEW

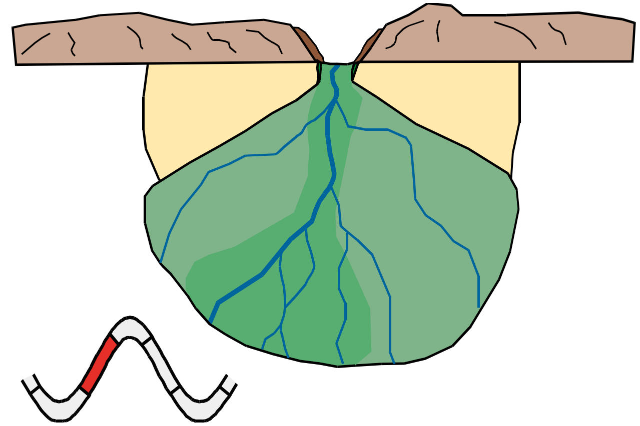


Weissmann, et al., 2002

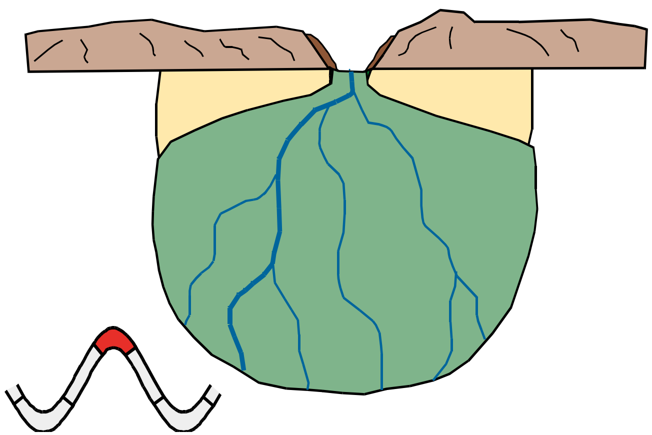
CYCLES ON SJV FLUVIAL FANS



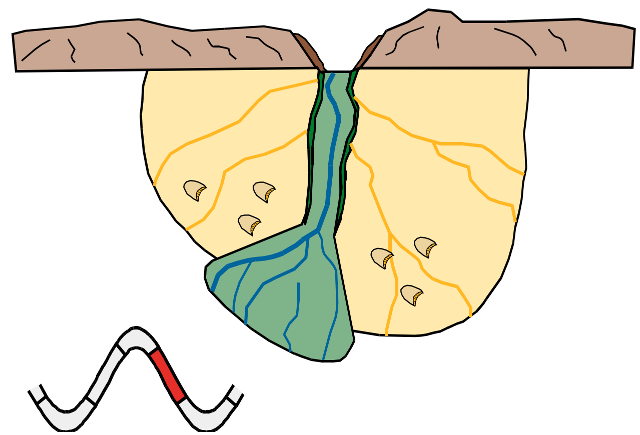
Late Interglacial



Glacial Outwash



Continued Glacial Outwash

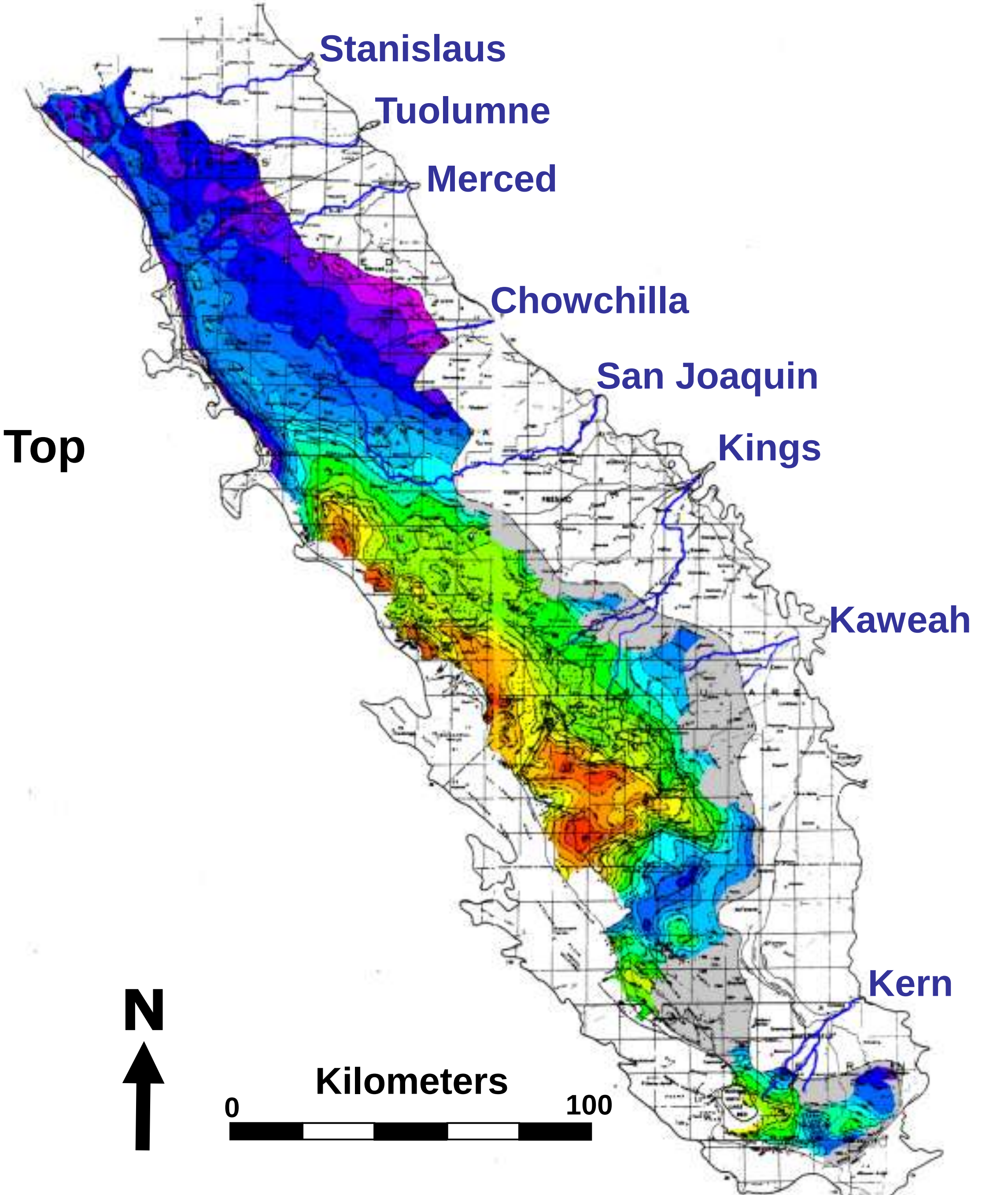


Glacial to Interglacial Transition

Weissmann et al. 2002

San Joaquin Basin

Depth to Corcoran Clay Top (Basin Structure)

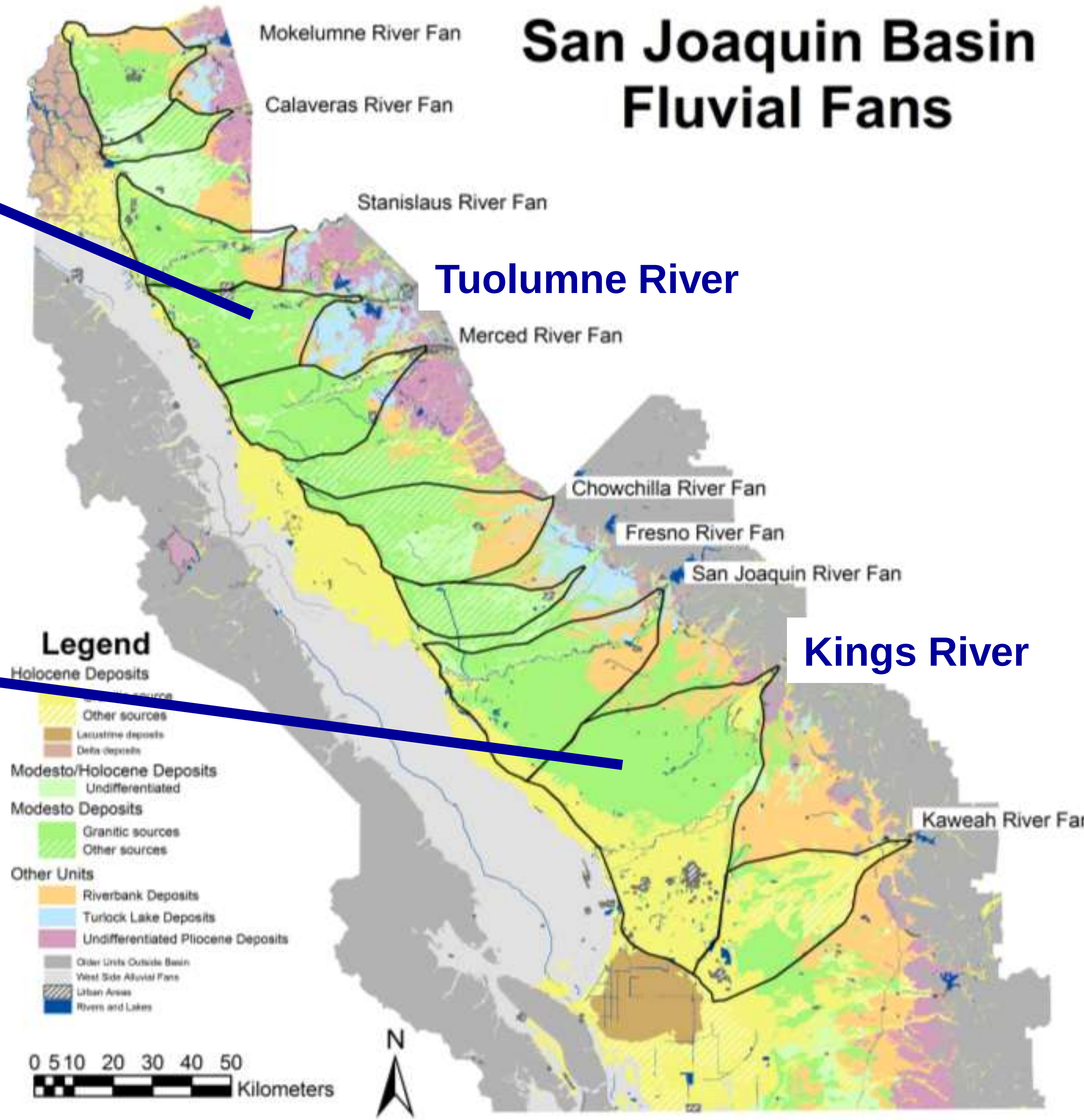


Lettis, 1982

San Joaquin Basin Fluvial Fans

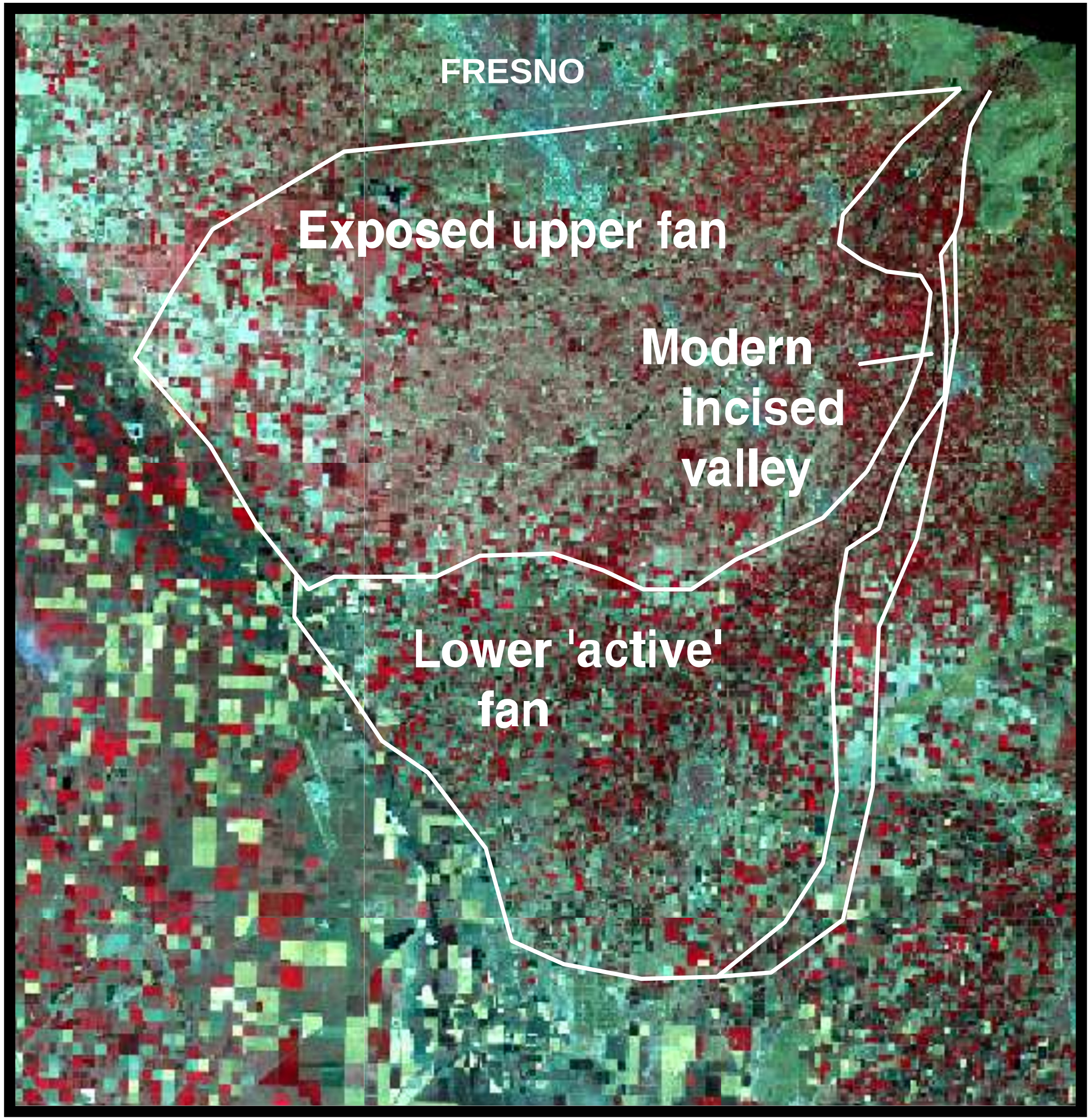
Tuolumne Fan:
- glacial input
- low subsidence rate
- low local base level

Kings River Fan:
- glacial input
- high subsidence rate
- high local base level



KINGS RIVER FLUVIAL FAN

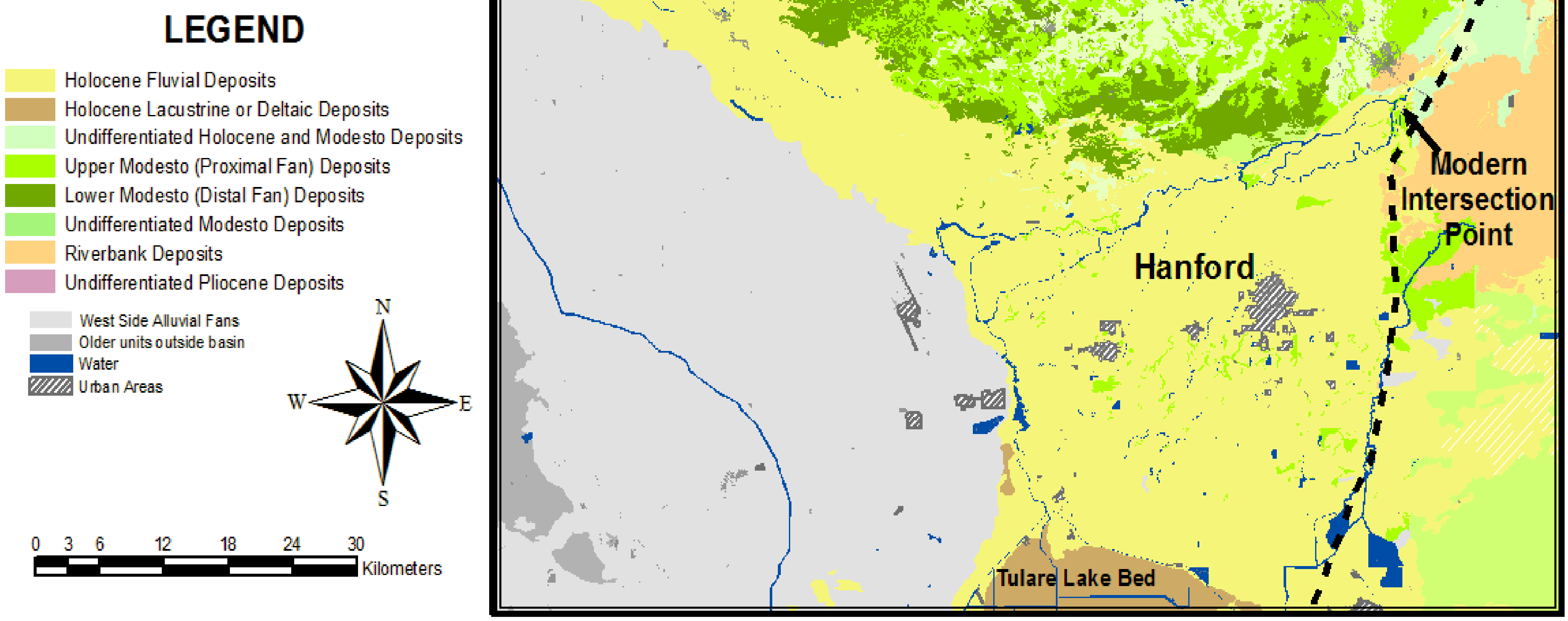
- glacial input
- high subsidence rate
- high local base level



20km

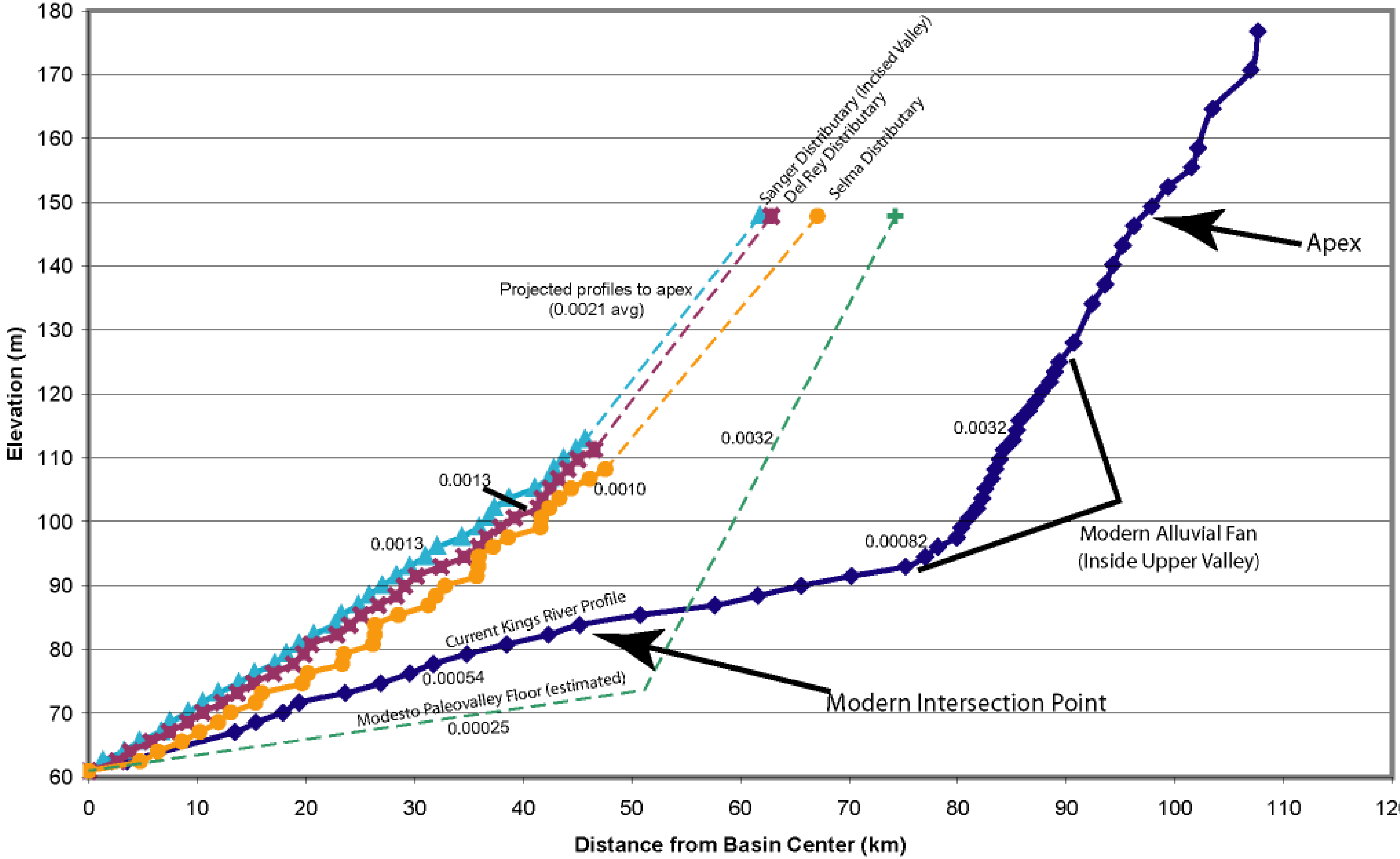
1980 Landsat MSS from USGS NALC program.

Kings River Fluvial Fan



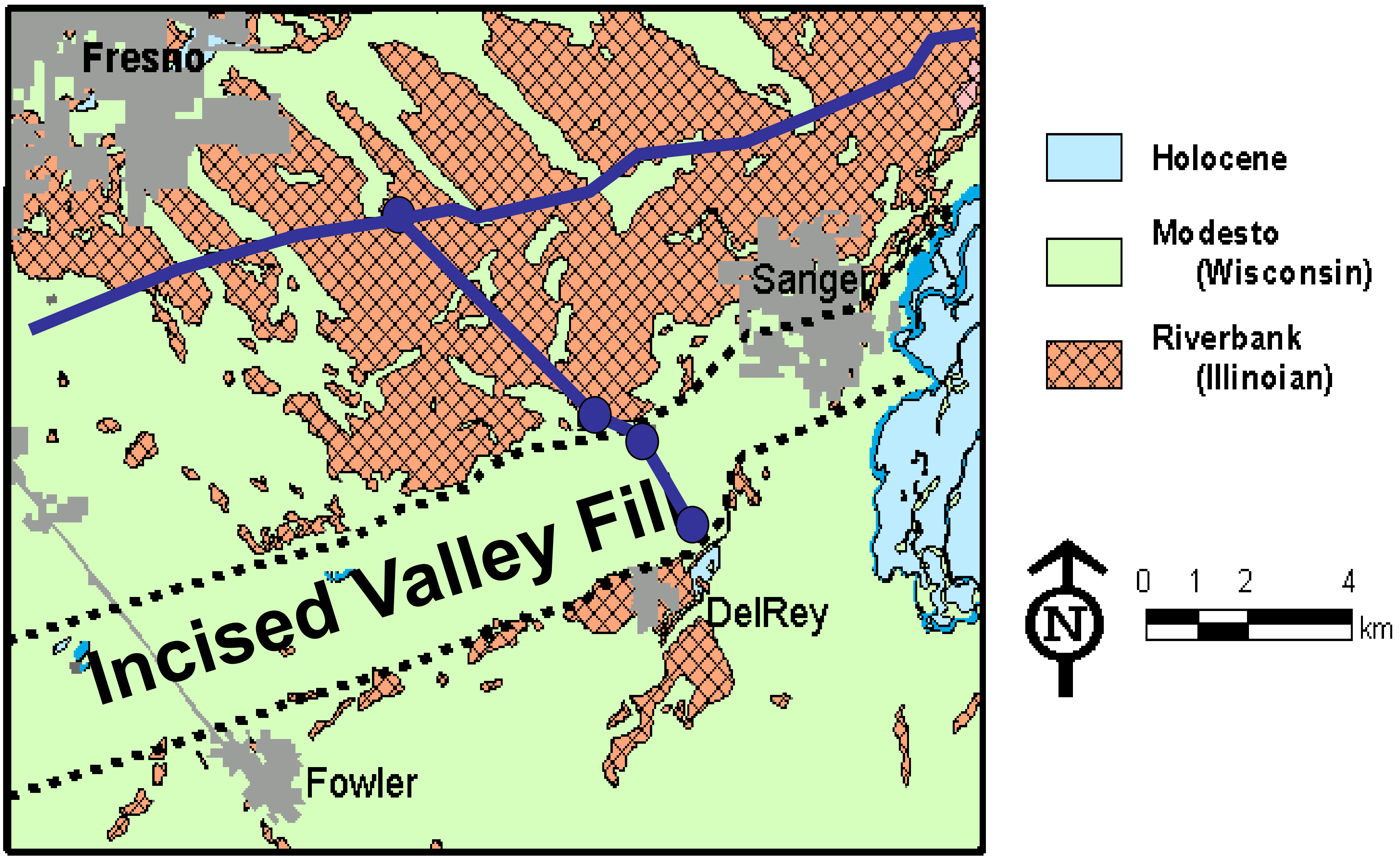
From Weissmann et al *2005*

Kings River Fluvial Fan Gradients



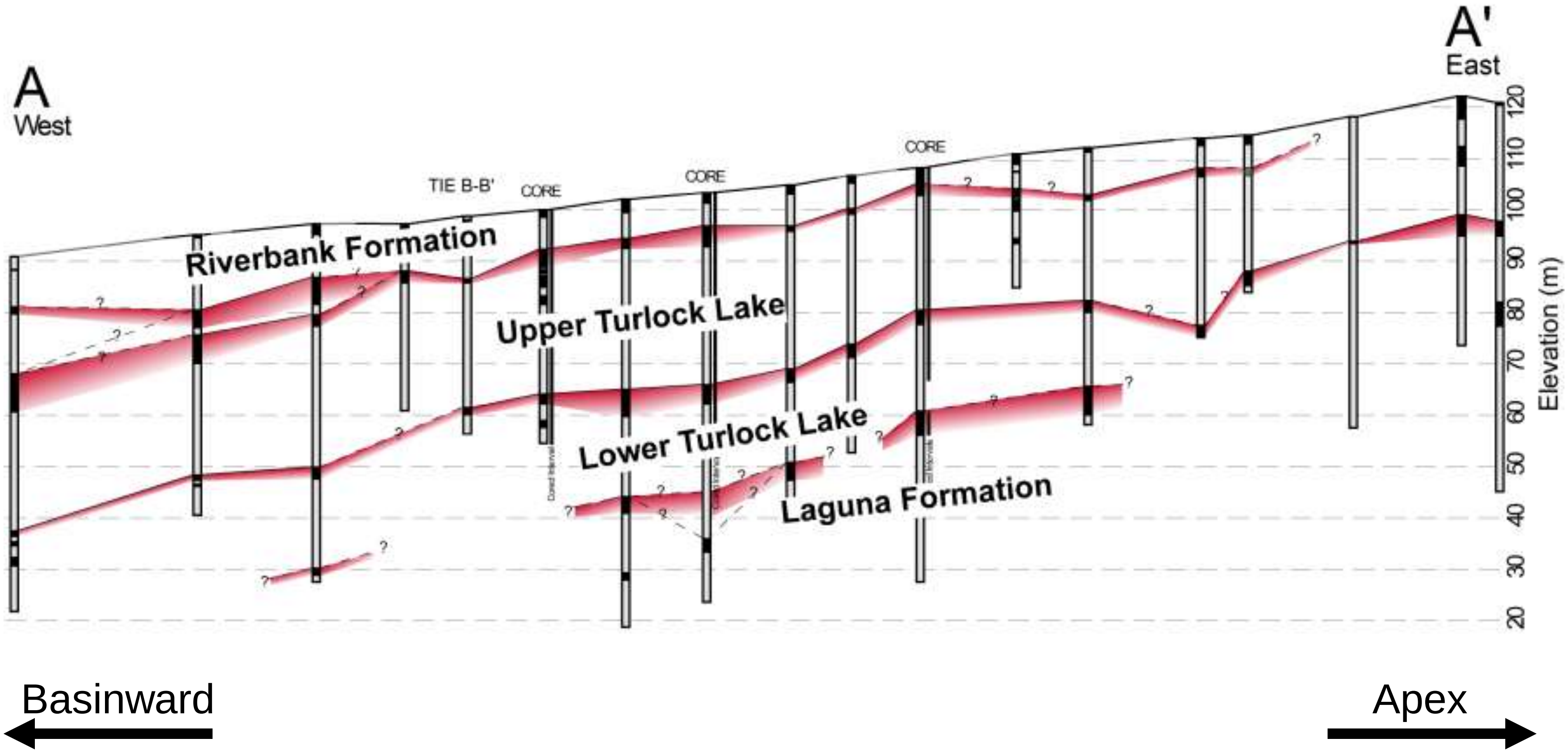
From Weissmann et al *2005*


8 m
18 m
25 ft
26 m
36 m
44 m
85 ft
115 ft
150 ft

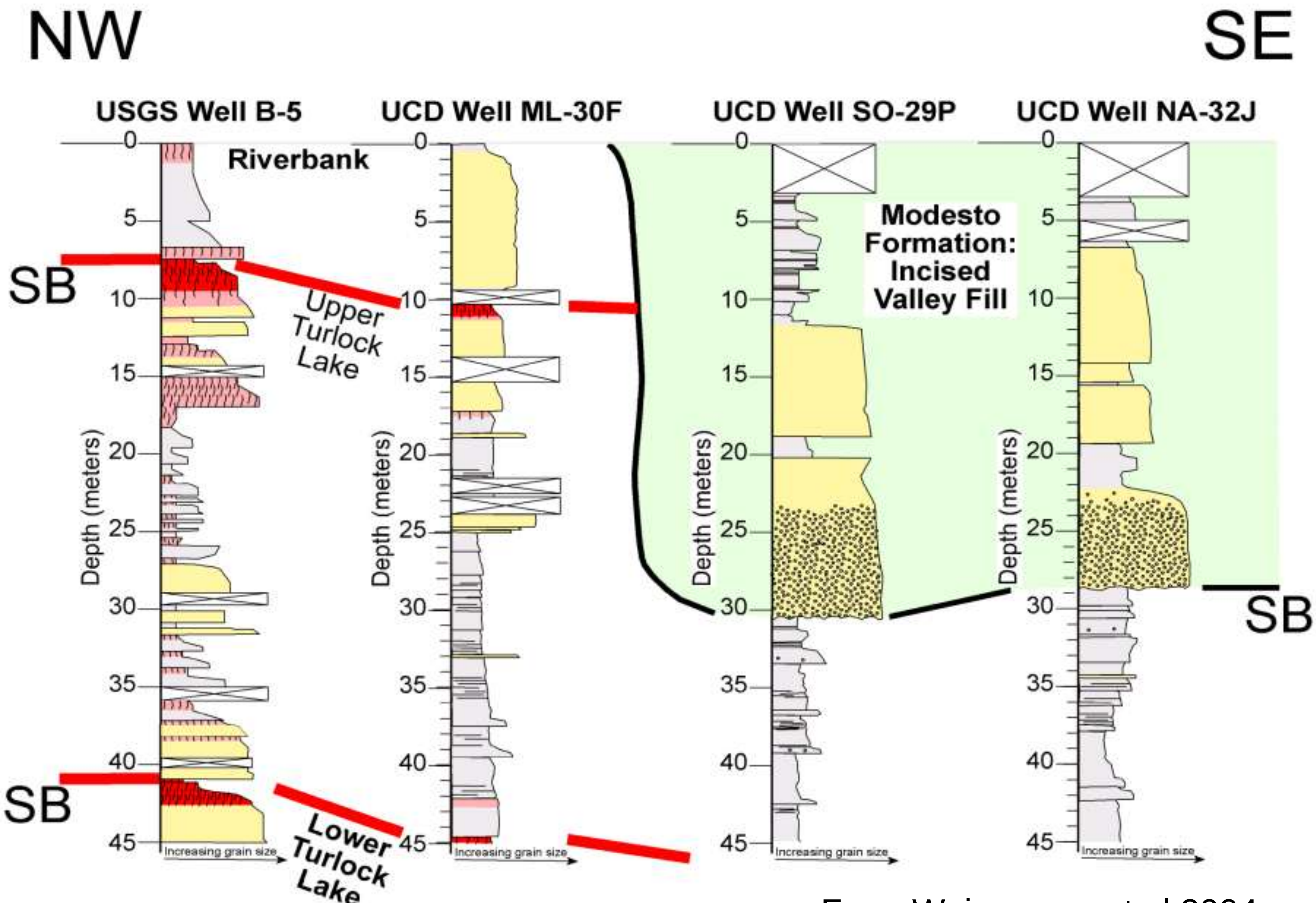


Fresno
Sanger
DelRey
Fowler
Incised Valley Fill
Holocene
Modesto (Wisconsin)
Riverbank (Illinoian)
N
0 1 2 4
km

Kings River Alluvial Fan – Dip Section



From Weissmann et al 2002

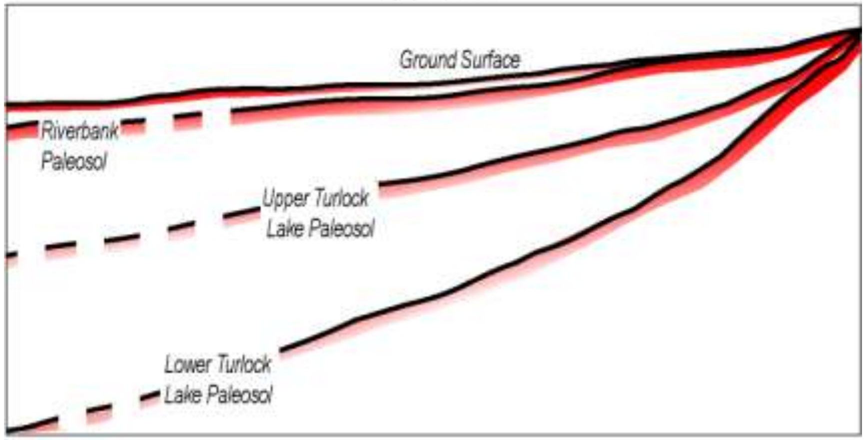


From Weissmann et al 2004

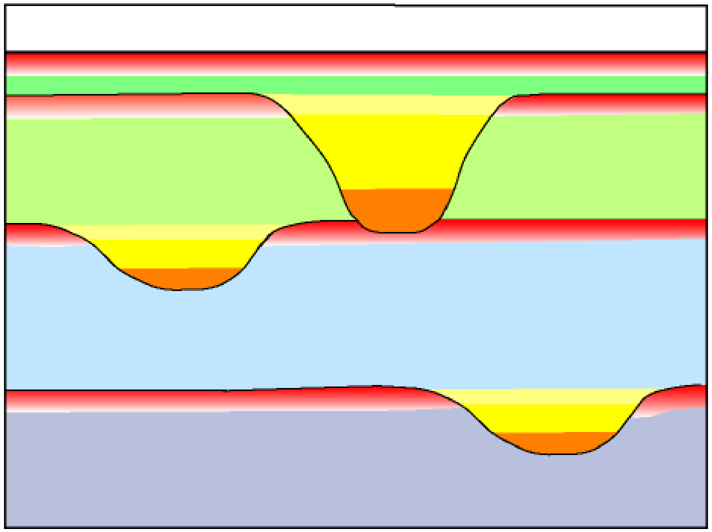
Kings River Fluvial Fan

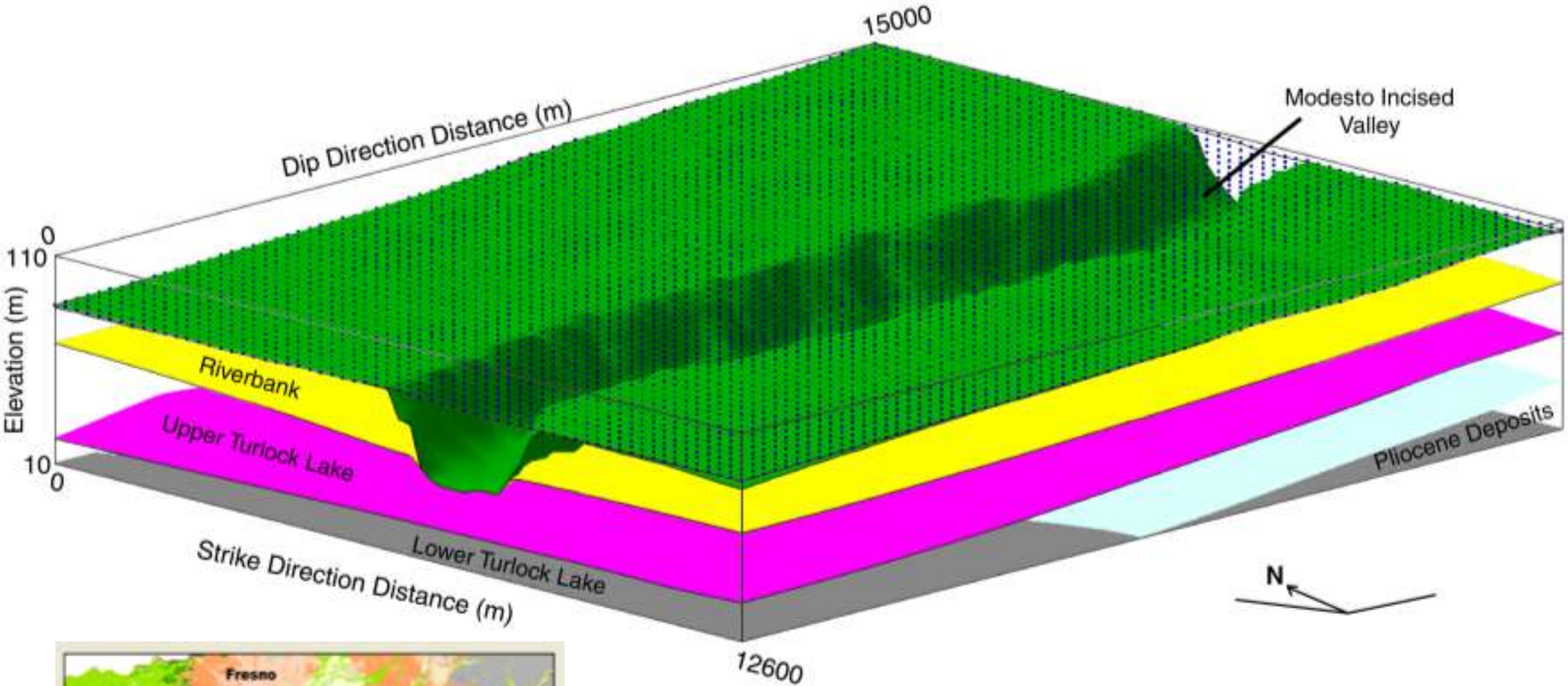
- Vertically-stacked sequences near apex
- Significant incised valley fill deposits, but modern incised valley is ~10m deep.
- Large, relatively thick open-fan fluvial deposits that radiate outward from intersection point near apex
- Preservation of interglacial deposits in basin
- Laterally extensive paleosols mark sequence boundaries.

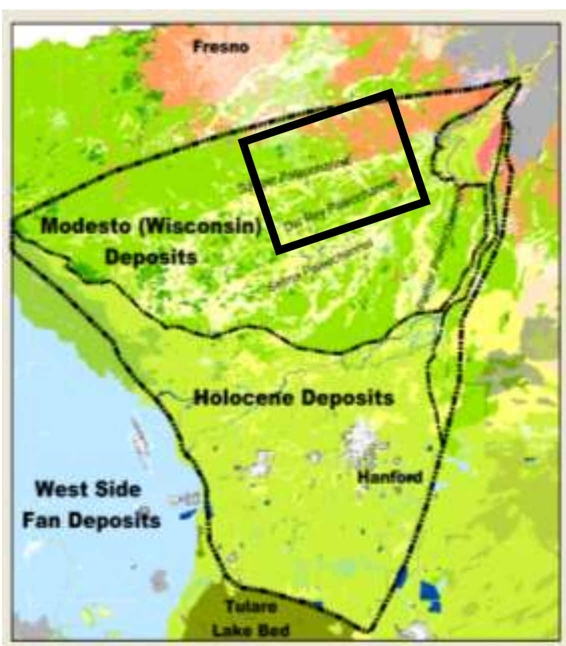
Dip Section



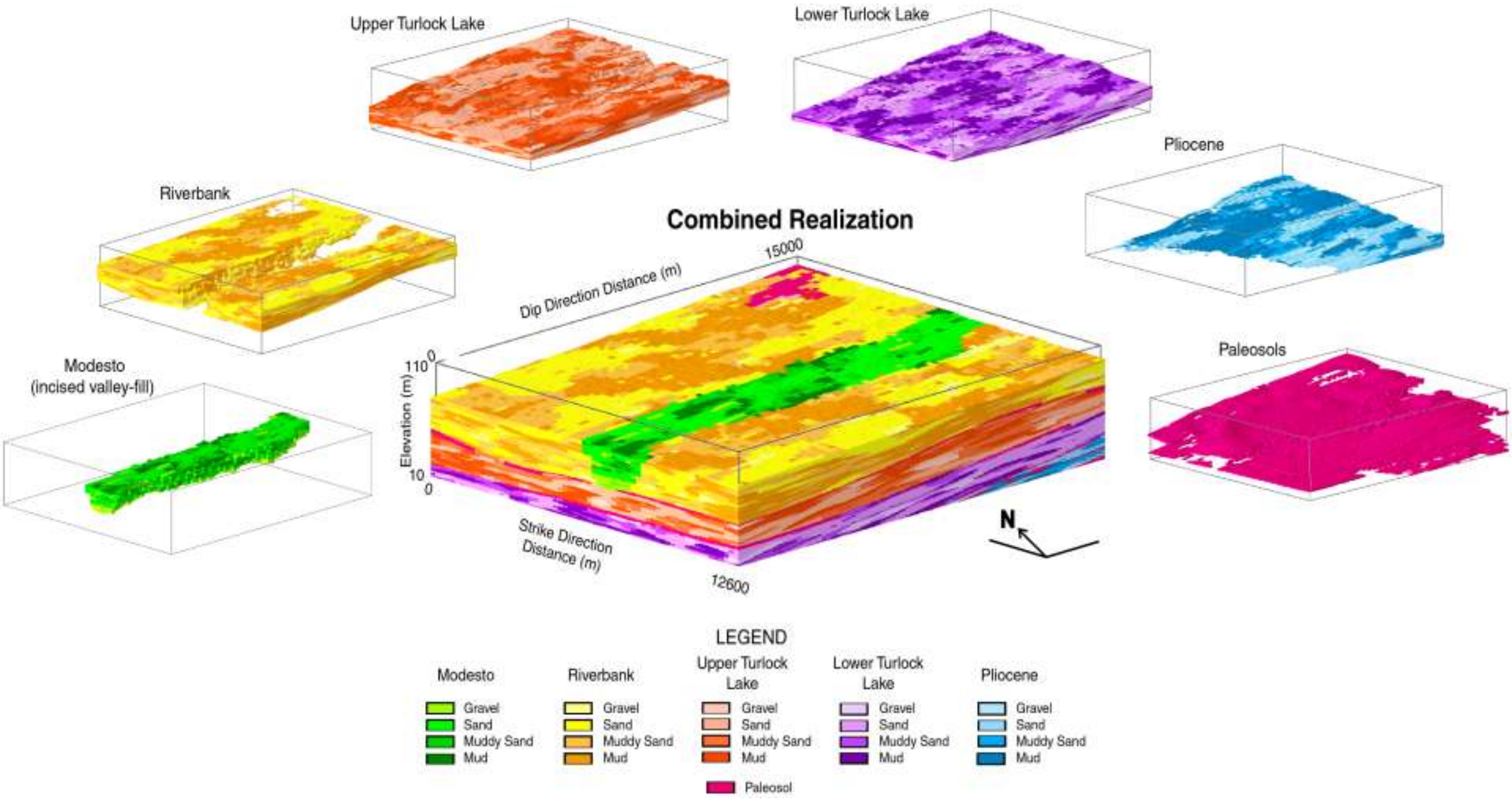
Strike Section





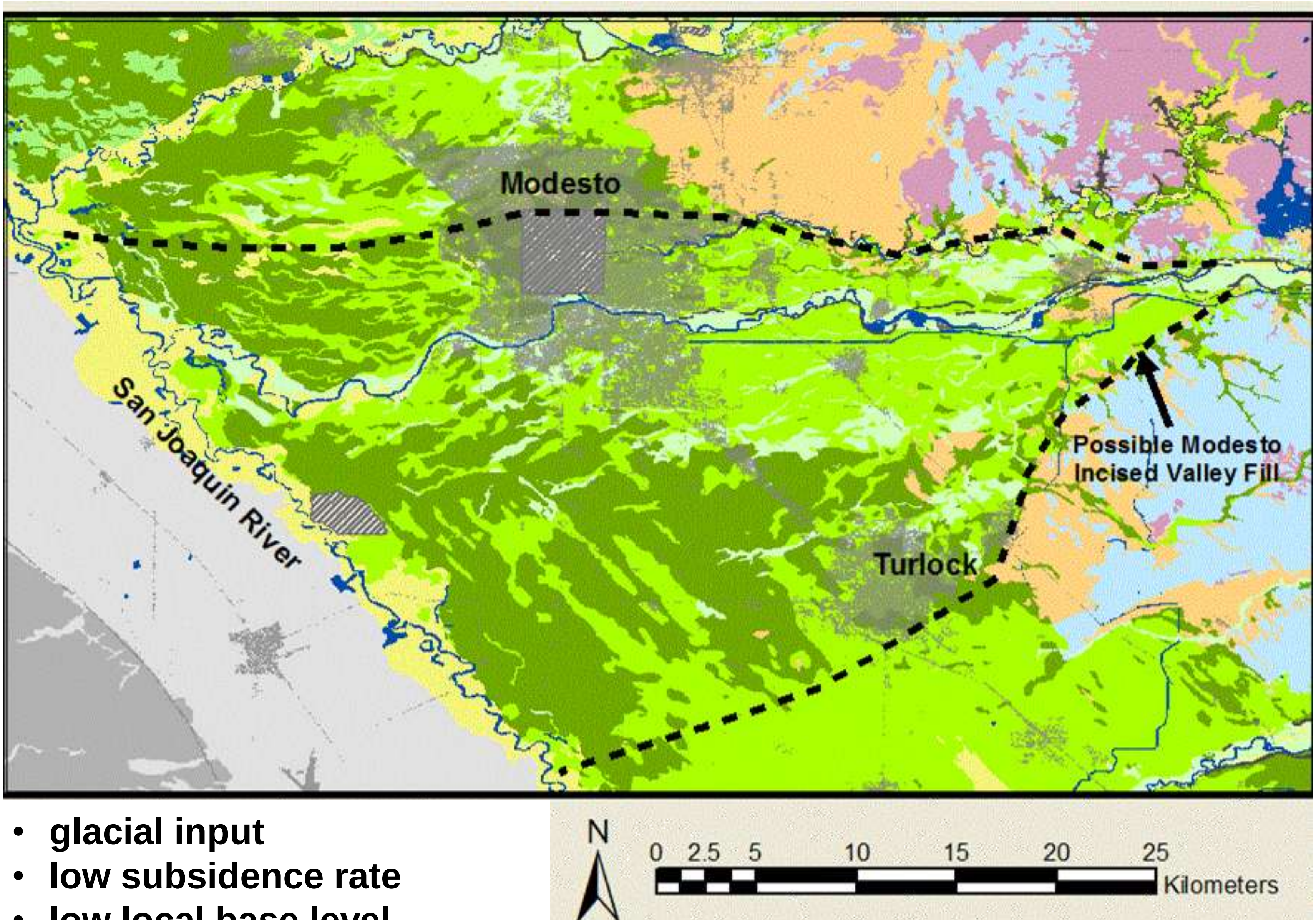


From Weissmann et al 2004



From Weissmann et al 2004

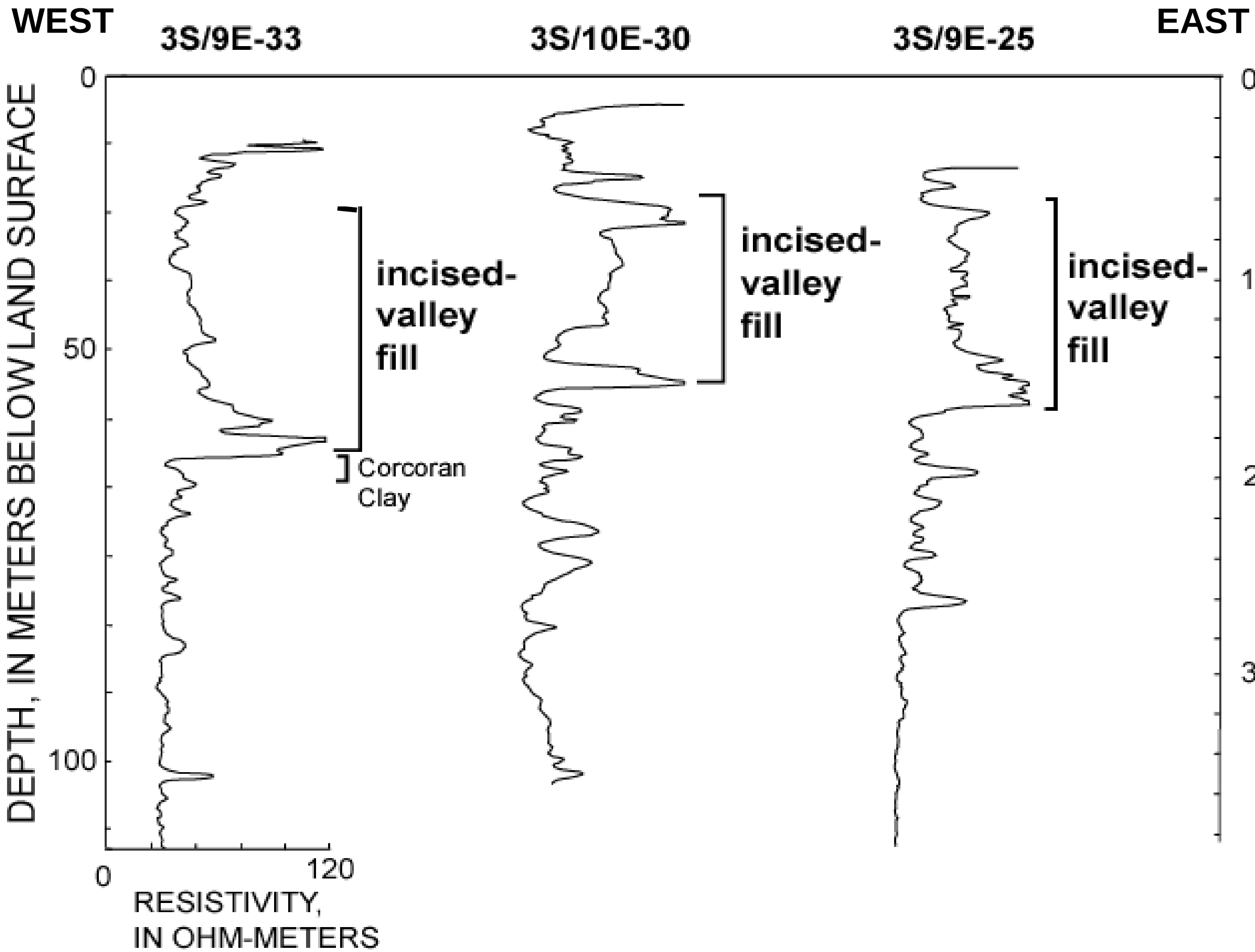
Tuolumne River Fluvial Fan



- **glacial input**
- **low subsidence rate**
- **low local base level**

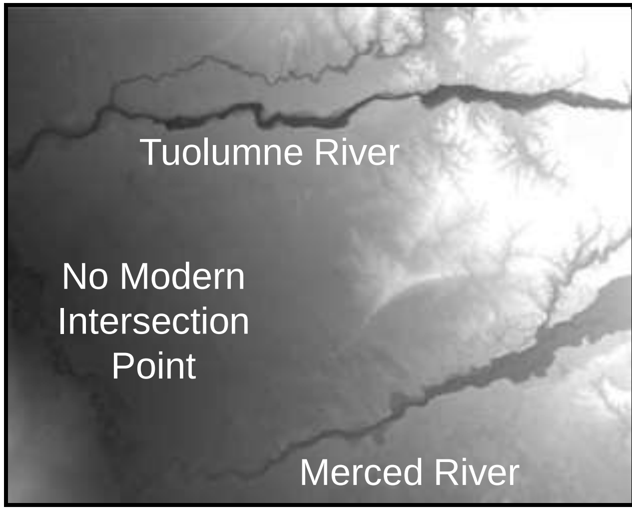
From Weissmann et al *2005*

Riverbank (?) Incised Valley Fill

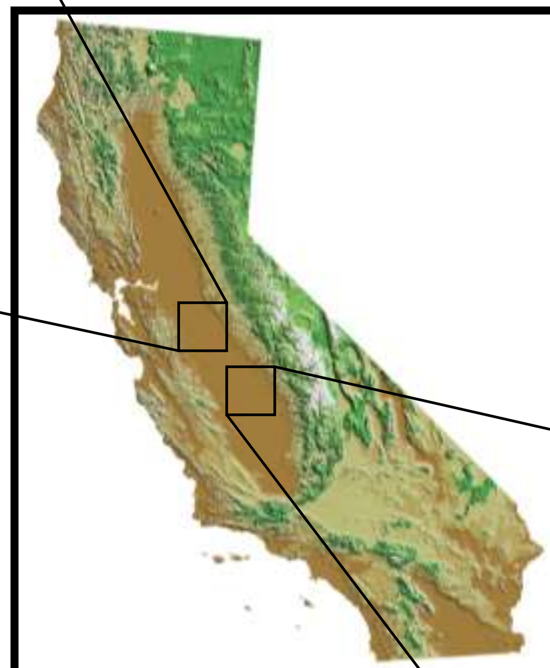


From Burow et al 2004

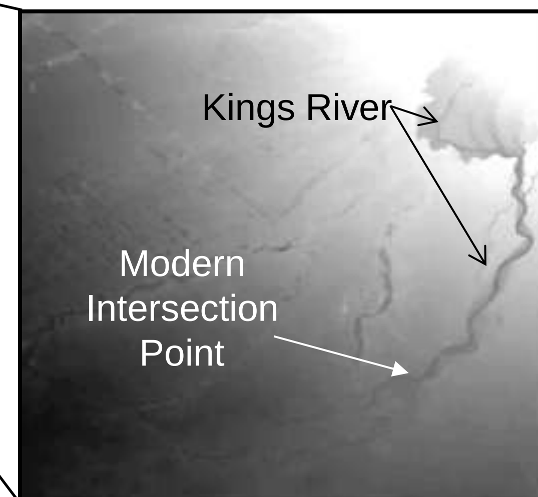
Modern Incised Valley Depths



Tuolumne and Merced River Fluvial Fans



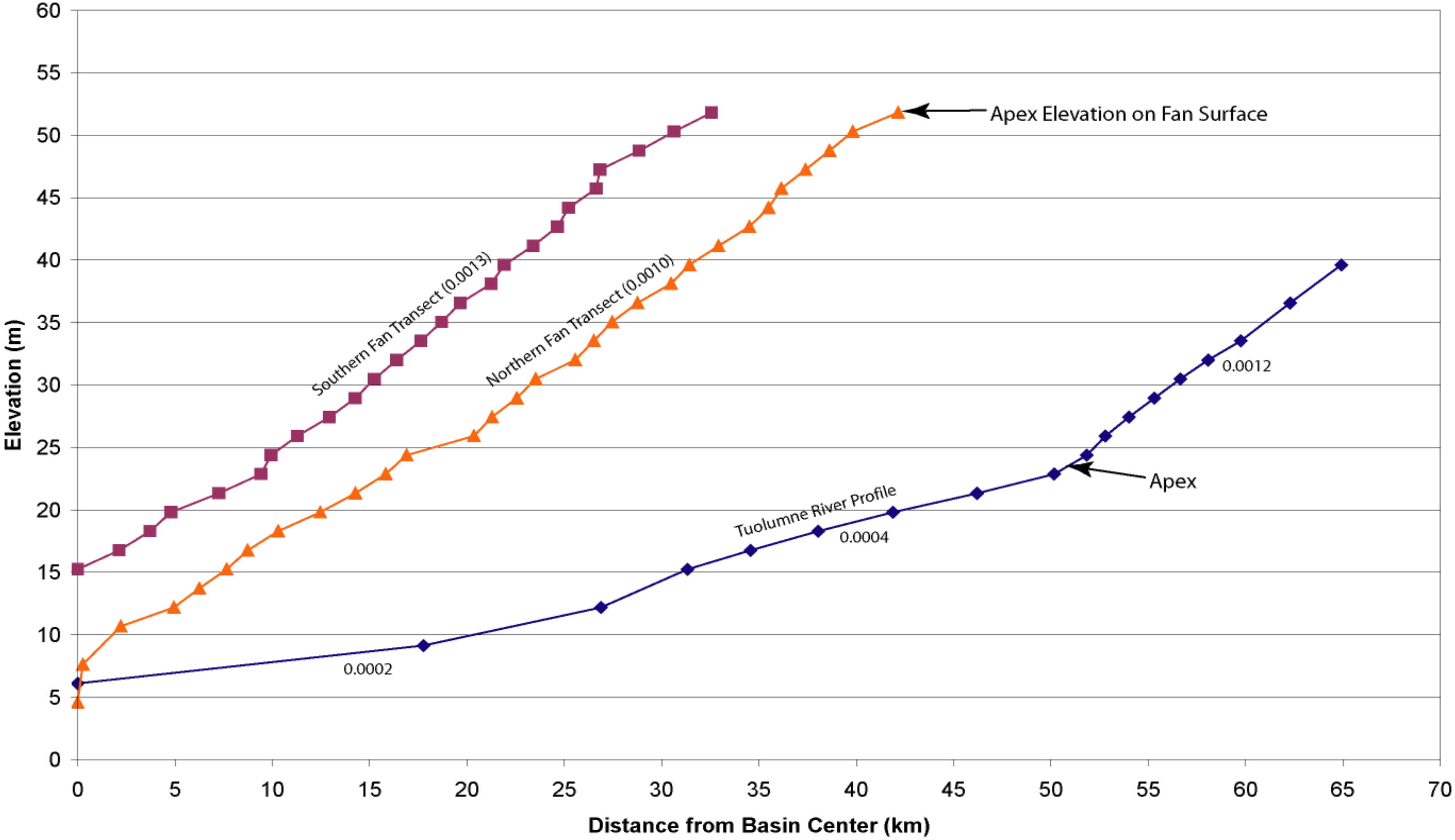
Kings River Fluvial Fan



Fluvial Fan Images from 30m USGS Digital Elevation Models

From Bennett 2003

Tuolumne River Fluvial Fan Gradients

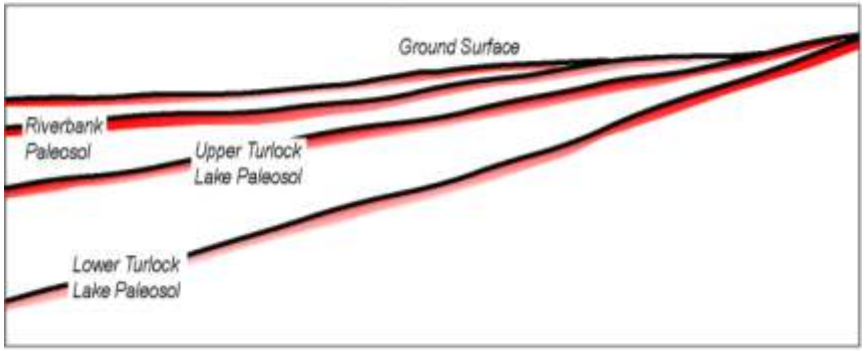


From Weissmann et al 2005

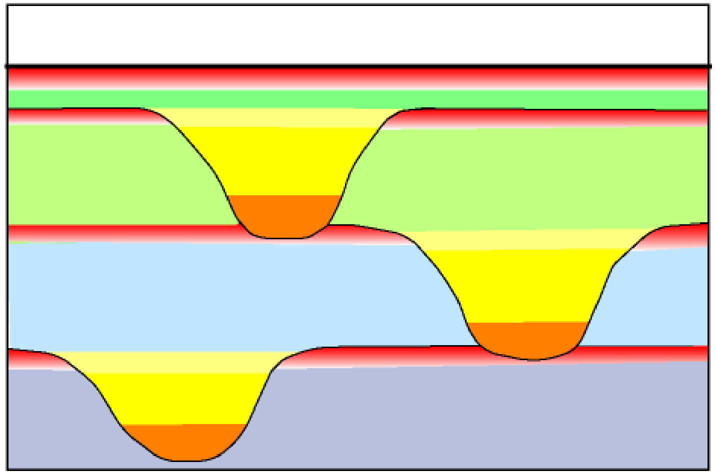
Tuolumne River Fluvial Fan

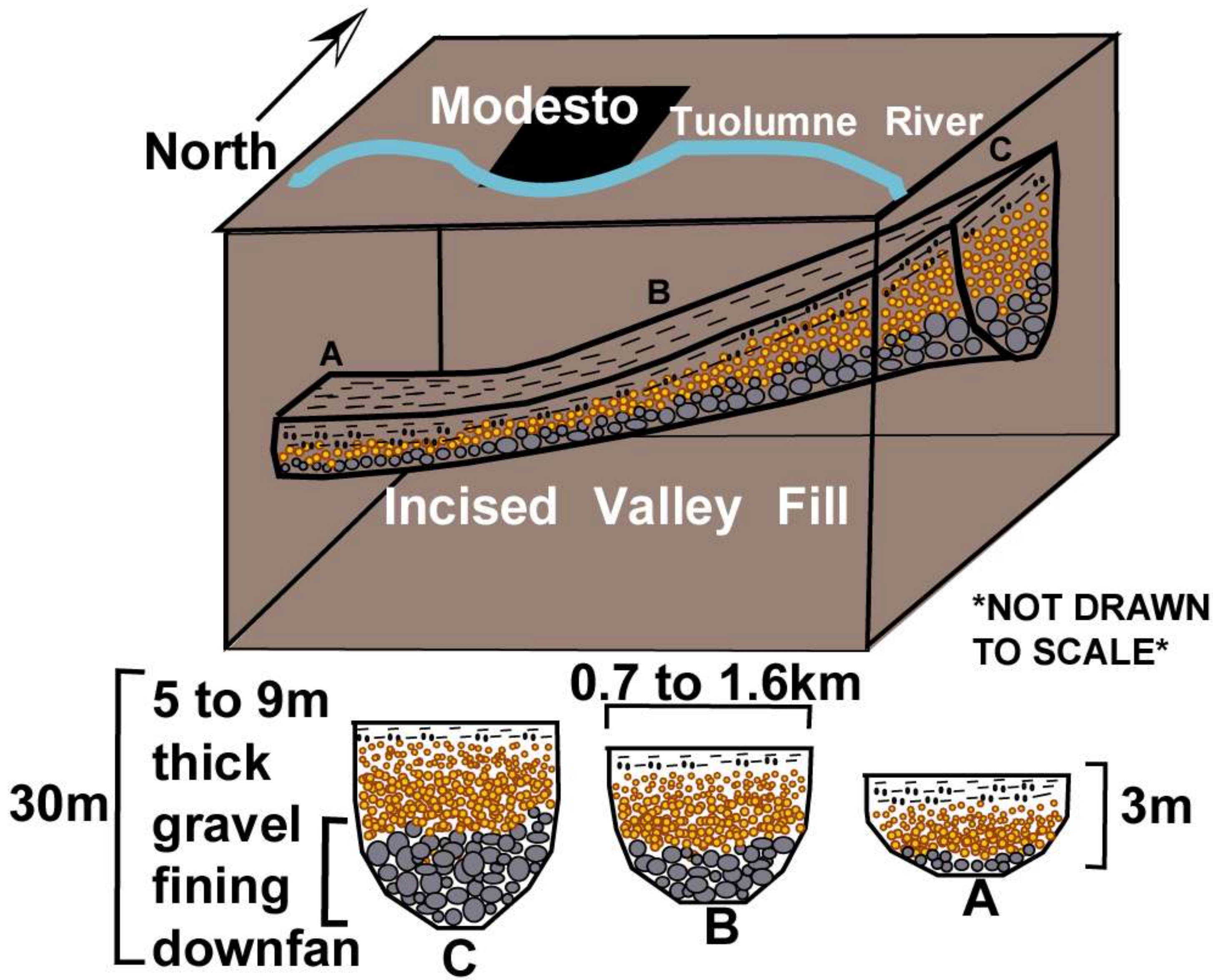
- **Laterally-stacked sequences basinward**
- **Significant incised valley fill deposits; modern incised valley is ~30m deep.**
- **Modesto open-fan fluvial deposits radiate outward from proximal intersection point but lack channels**
- **No preservation of interglacial deposits in distal fan**

Dip Section



Strike Section



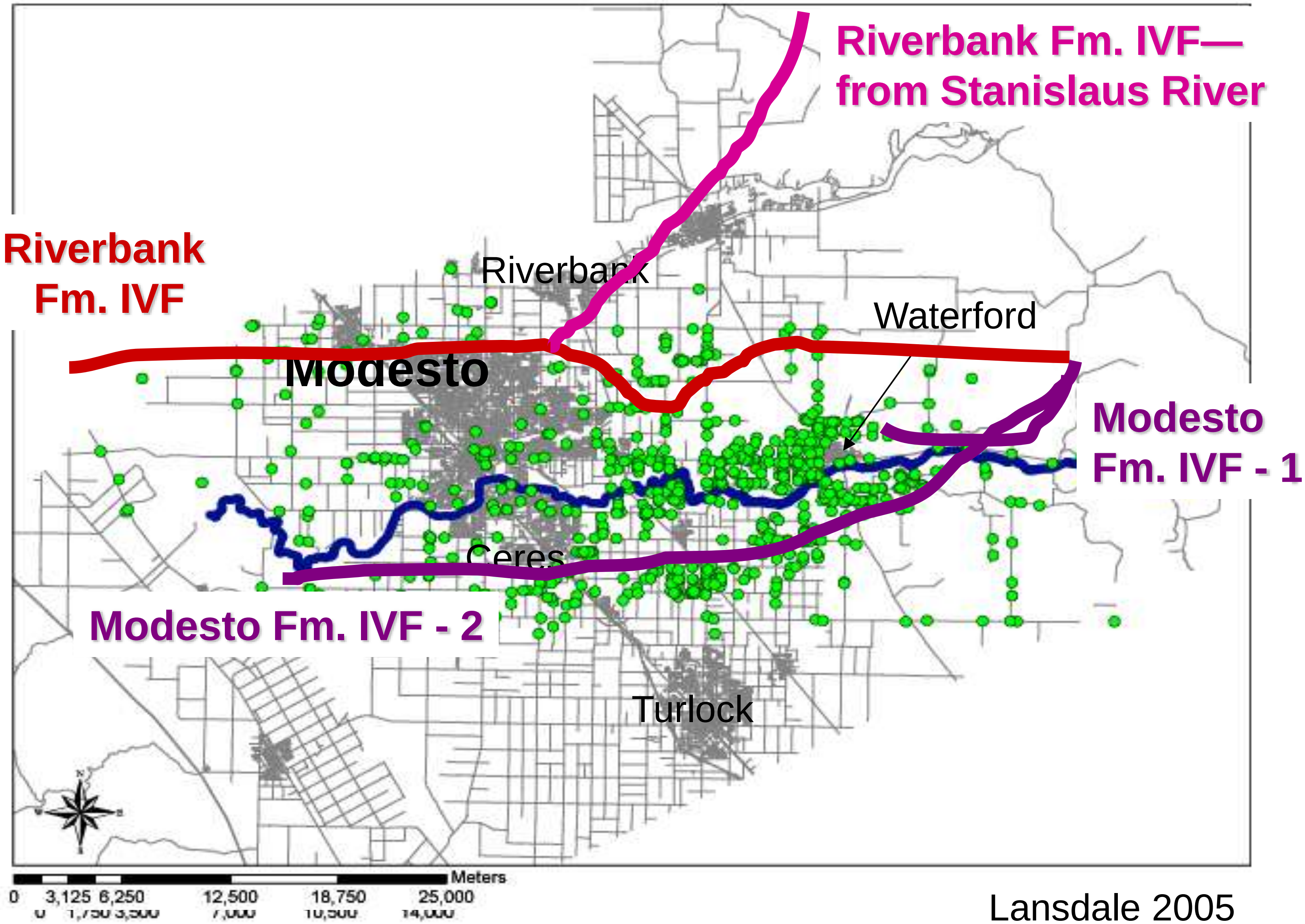

North
Modesto
Tuolumne River
C
B
A
Incised Valley Fill
NOT DRAWN TO SCALE
0.7 to 1.6km
30m
5 to 9m thick gravel fining downfan
3m
C
B
A

Determining the Location of the Tuolumne Incised Valley Fills

- Evaluated over 10,000 driller's well logs to locate the gravel/cobble base of the IVF.

1. Gravels > 3 meters thick
2. Gravel depths were used to correlate trends:
   - 24 to 38 m (80 to 125 ft): Modesto IVF
   - 43 to 61 m (~140 to 180 ft): Riverbank IVF
3. Rank of 1 (best) to 4 (worst): fining-upward character of the IVF, drilling method, and driller.

Wells with Possible Incised Valley Fill Indicators



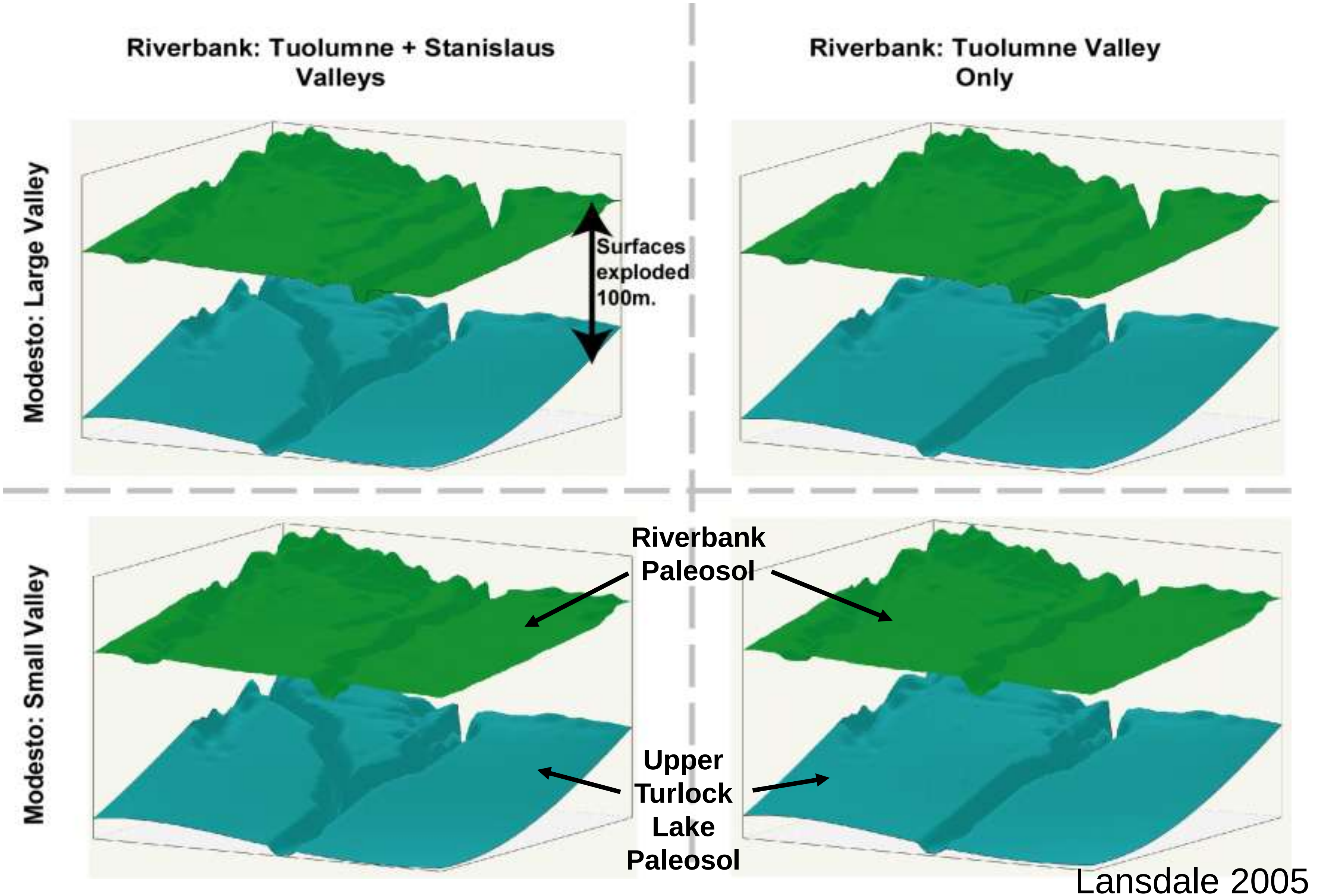
Lansdale 2005

Modeling Applications
San Joaquin Valley Fluvial Fans

1. **Non-point Source Contamination: Evaluation of Groundwater Age Date from Chlorofluorocarbons (CFC)**
   - **Weissmann *et al.* 2002, Water Resources Research, v. 38**

2. **Water Supply / Non-point Source Contamination: Groundwater Flow and Contaminant Transport Around Incised Valley Fill Sediments**
   - **Weissmann *et al.* 2004, SEPM Special Publication 80**
   - **Lansdale 2005, MS Thesis, Michigan State University**

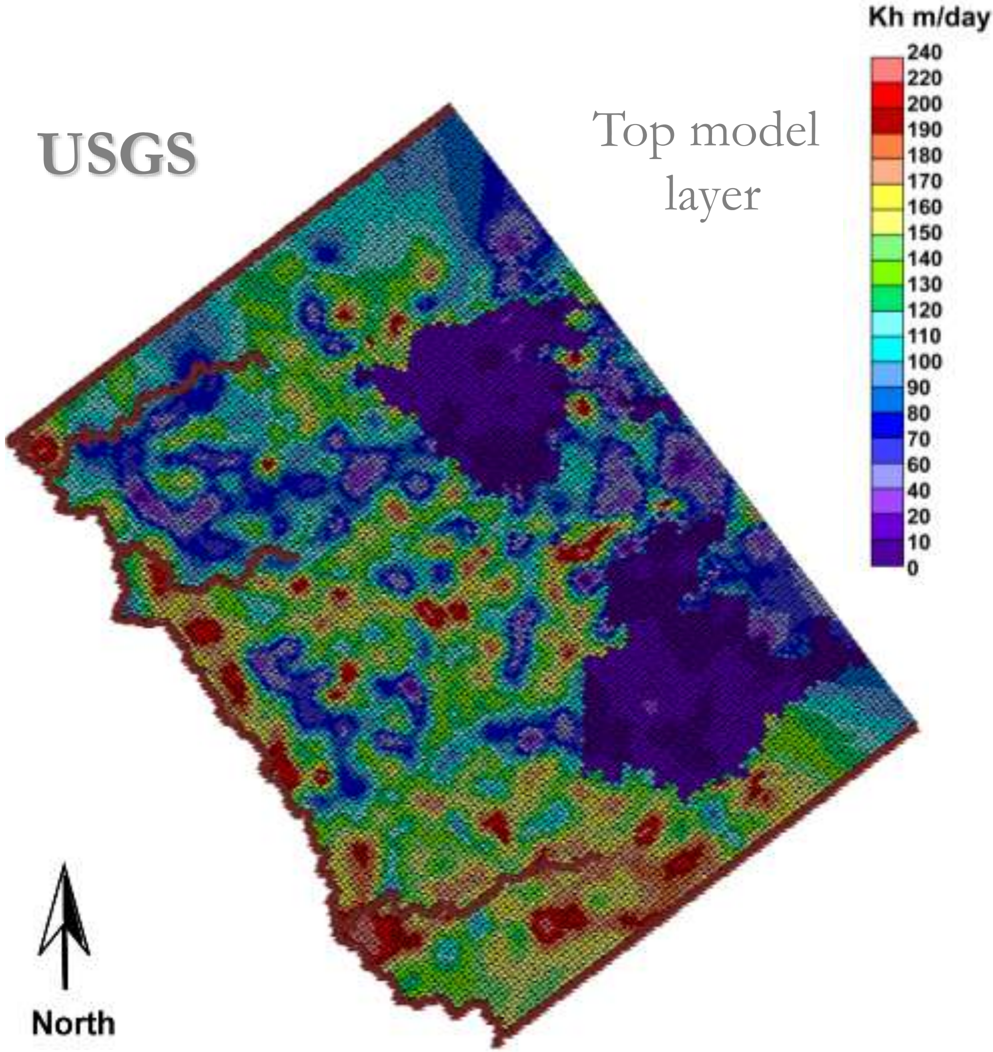
Incised Valley Fill Models – Modesto Area



Lansdale 2005

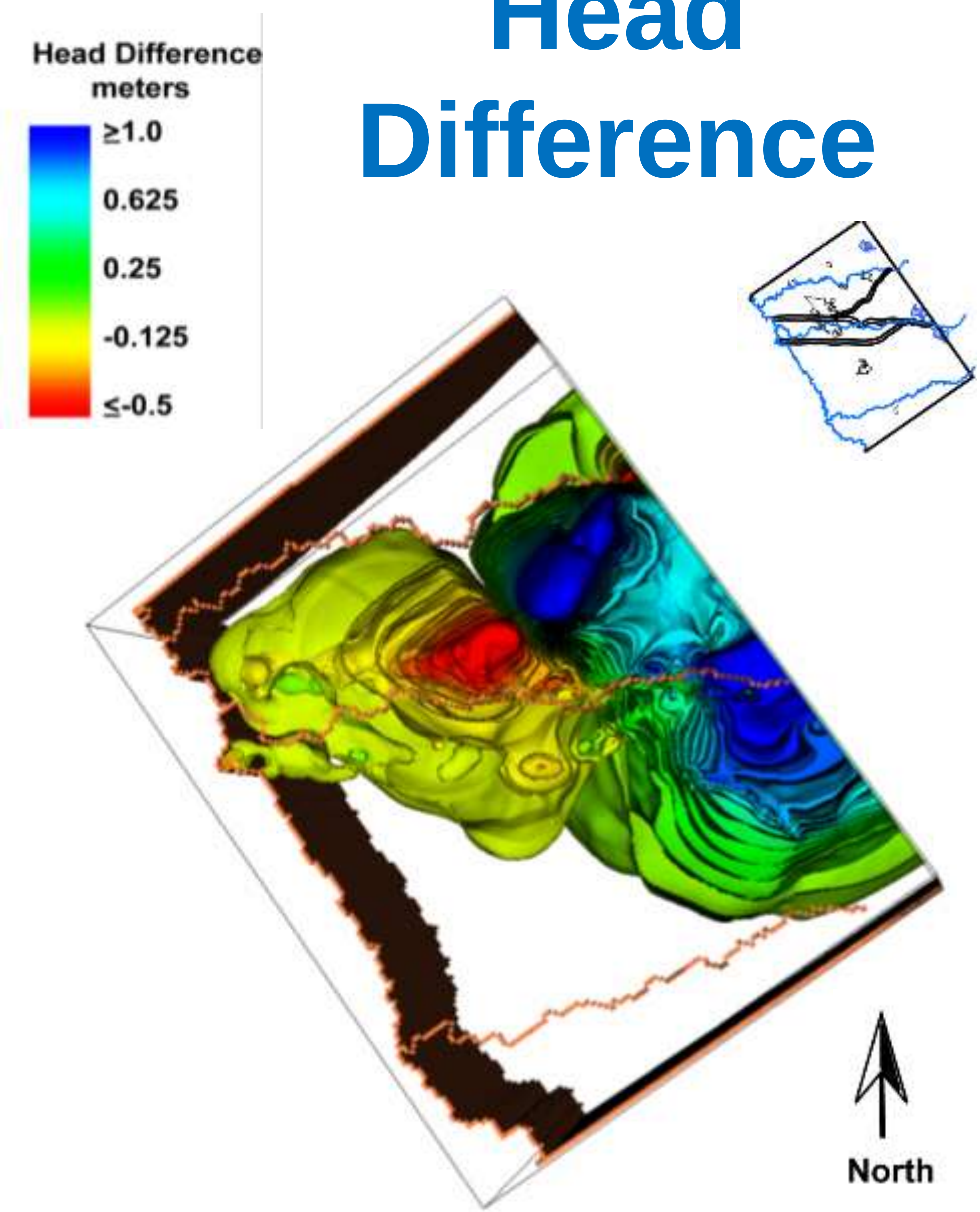
Groundwater Model Development: USGS Model and Modifications

- MODFLOW 2000
- Characterization of Geology (Hydraulic conductivities)
  - USGS Model
    - Binary texture (grain-size) classification from driller's logs
    - Calculated equivalent K values
    - Preserves heterogeneity
  - Modification
    - Addition of the IVFs



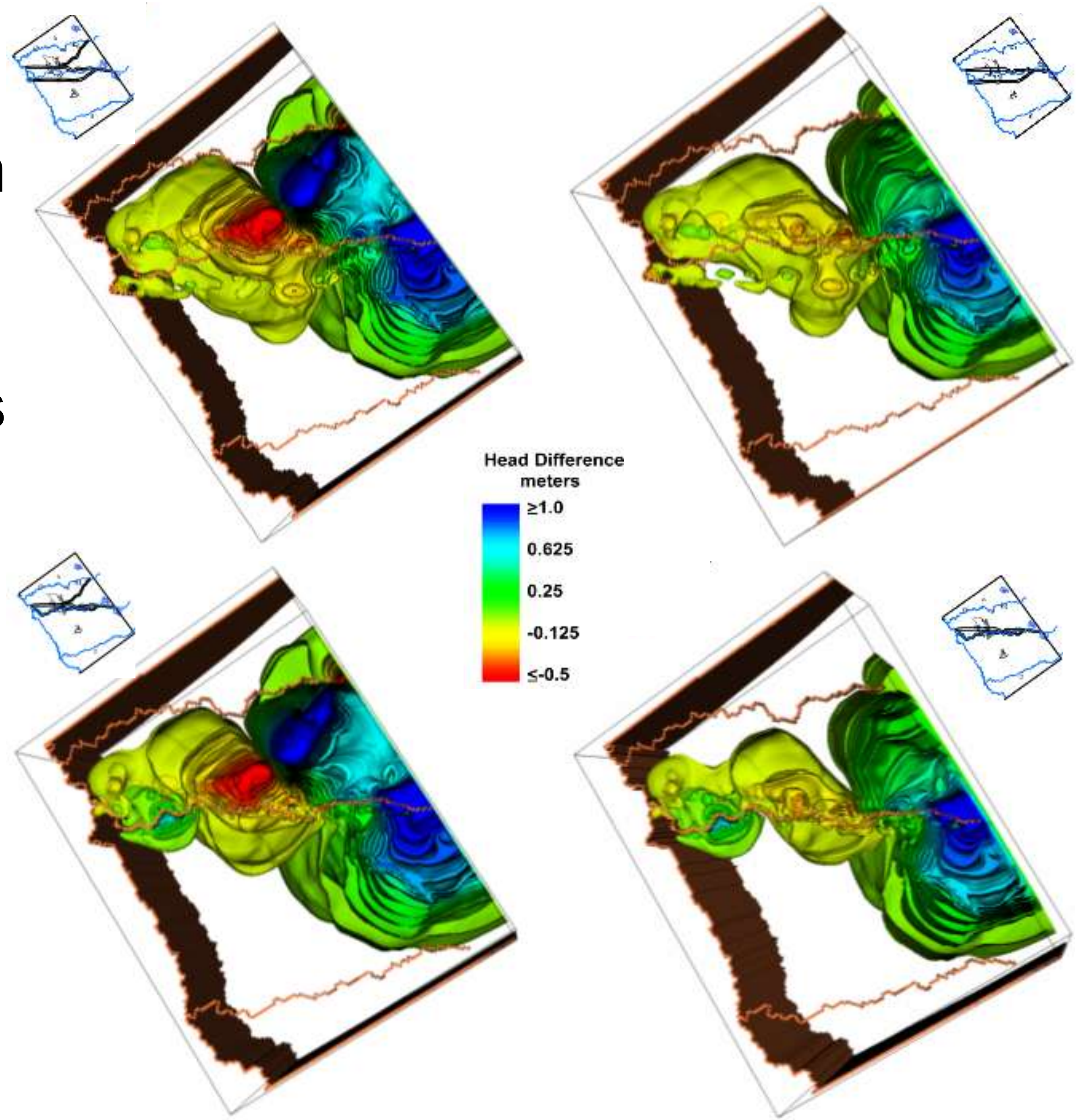
Head Difference

- **Head difference** = (model without IVF) – (model with the IVF)
- **Positive head difference** (blues and greens)
  - no IVF model head <u>HIGHER</u> than IVF model head
- **Negative head difference** (reds and yellows)
  - no IVF model head <u>LOWER</u> than the IVF model head
- Areas of convergent and divergent flow



Lansdale 2005

Comparison among Geologic Realizations

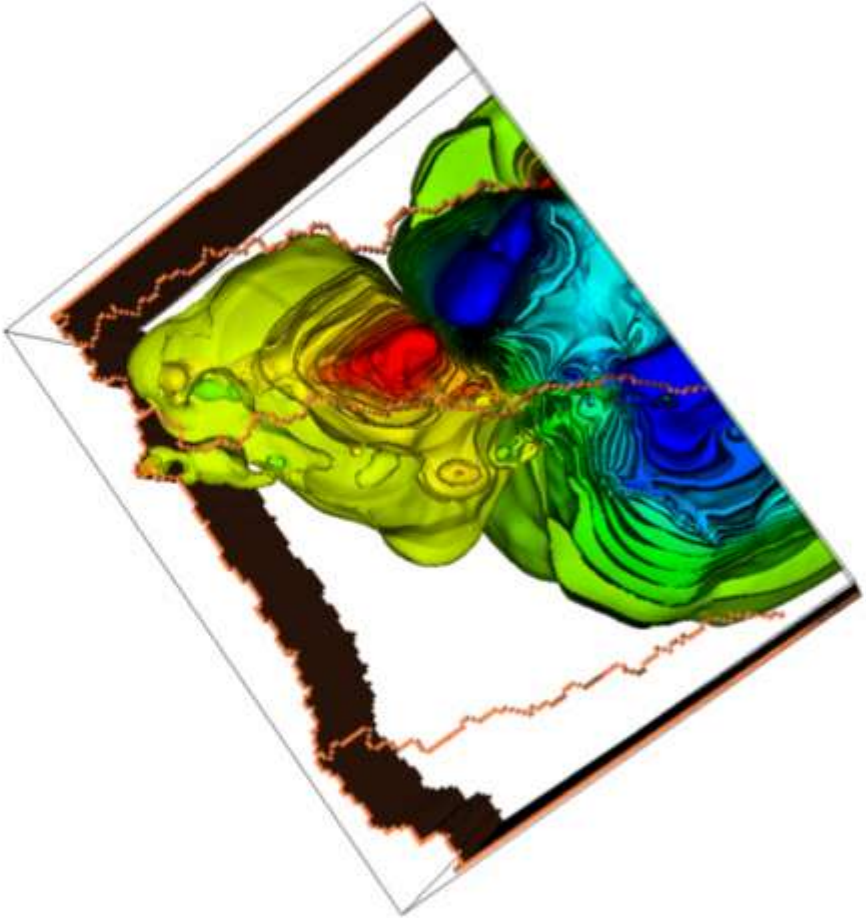


Lansdale 2005

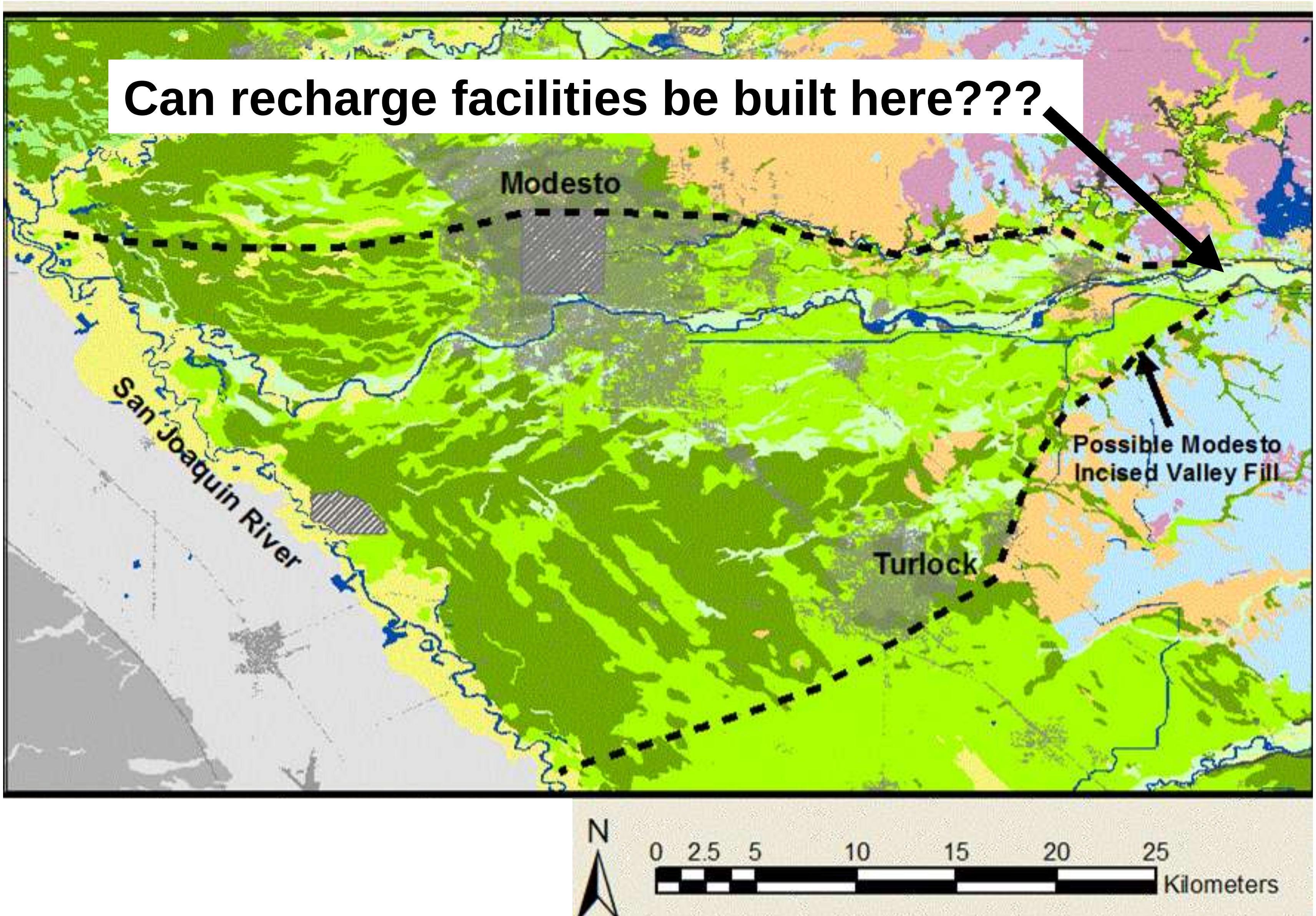
Implications for Artificial Recharge

Incised valley fill deposits are potential pipelines for transferring water deep into the aquifer…if we can access them!

BUT, these incised valley fill units don't exist on all megafans!



Tuolumne River Fluvial Fan



From Weissmann et al *2005*

Concluding Thoughts

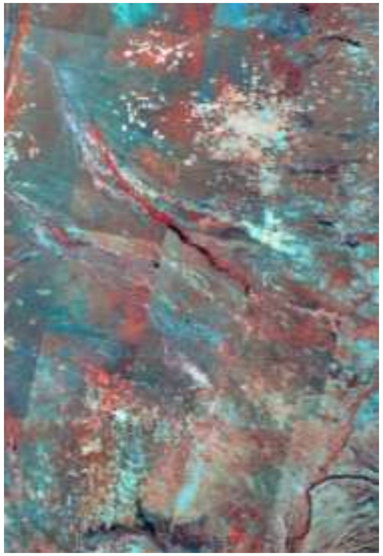
- **Stratigraphic framework is critical for:**
  - **Understanding aquifer test results**
  - **Modeling contaminant transport**
  - **Evaluating non-point source contaminant movement**
  - **Developing water supply (e.g., artificial recharge)**
- **Further work is needed on the San Joaquin Basin megafans to determine potential for artificial recharge through incised valley fill deposits.**
- **San Joaquin Basin megafans may provide a framework from which to understand other DFS.**

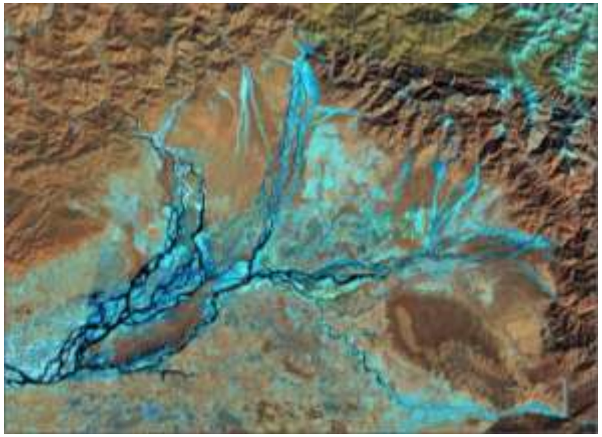
Concluding Thoughts

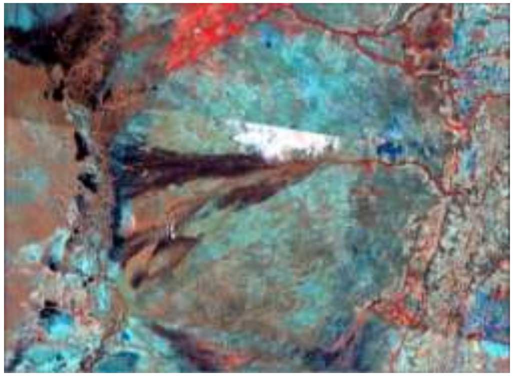
- **Rivers in continental sedimentary basins exist either as distributive fluvial systems (DFS) or as axial or interfan tributive streams**
- **DFS dominate basin depositional surface area, covering more than 90% of the fluvial depositional area.**
- **THEREFORE: We believe that most of the fluvial sedimentary rock record was formed by distributive fluvial systems.**
- **However: Some important sedimentary successions are tributary (axial or initial valley fill).**

Concluding Thoughts

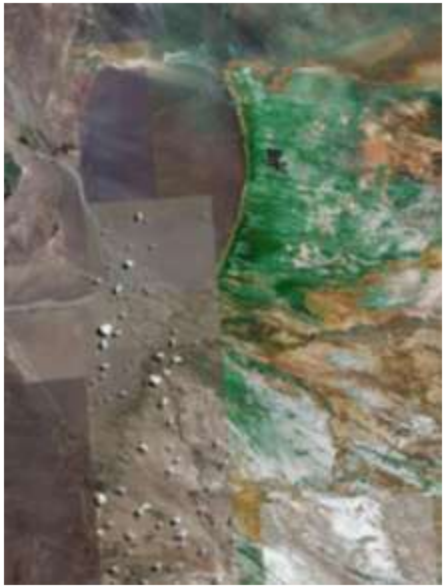
- DFS depositional patterns and resulting facies distributions are potentially different from the tributary stream systems we typically used to develop facies models (or, the facies models are out of context of the basin).
- A predictive pattern of facies exist from DFS deposition.
- We need to evaluate the geomorphology of DFS and deposits from these rivers in order to construct facies models for rock record evaluation.

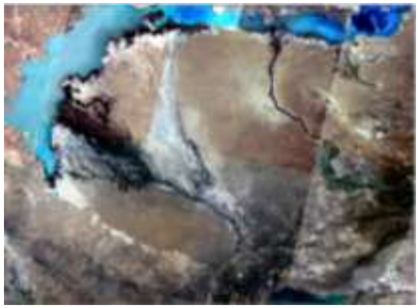


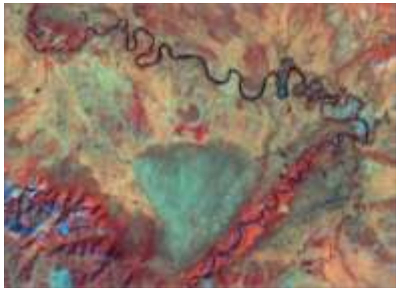




We need to focus on the rivers that deposit material in sedimentary basins







Sedimentary Basin Work

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Postdoc: Stephanie Davidson

Students: Michelle Olson; Kelsey McNamara; Amanda Owen; Anna Kulikova; Proma Bhattacharyya; Holly Buehler; Lauren Massengill; Reyna Banteah; Kevin Painter; Cody Bodman; Franki Anaya; Manny Salgado

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National Science Foundation

University of New Mexico

San Joaquin Basin Work

Graduate Students:

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Amy Lansdale (MS 2005)

Undergraduate Students:

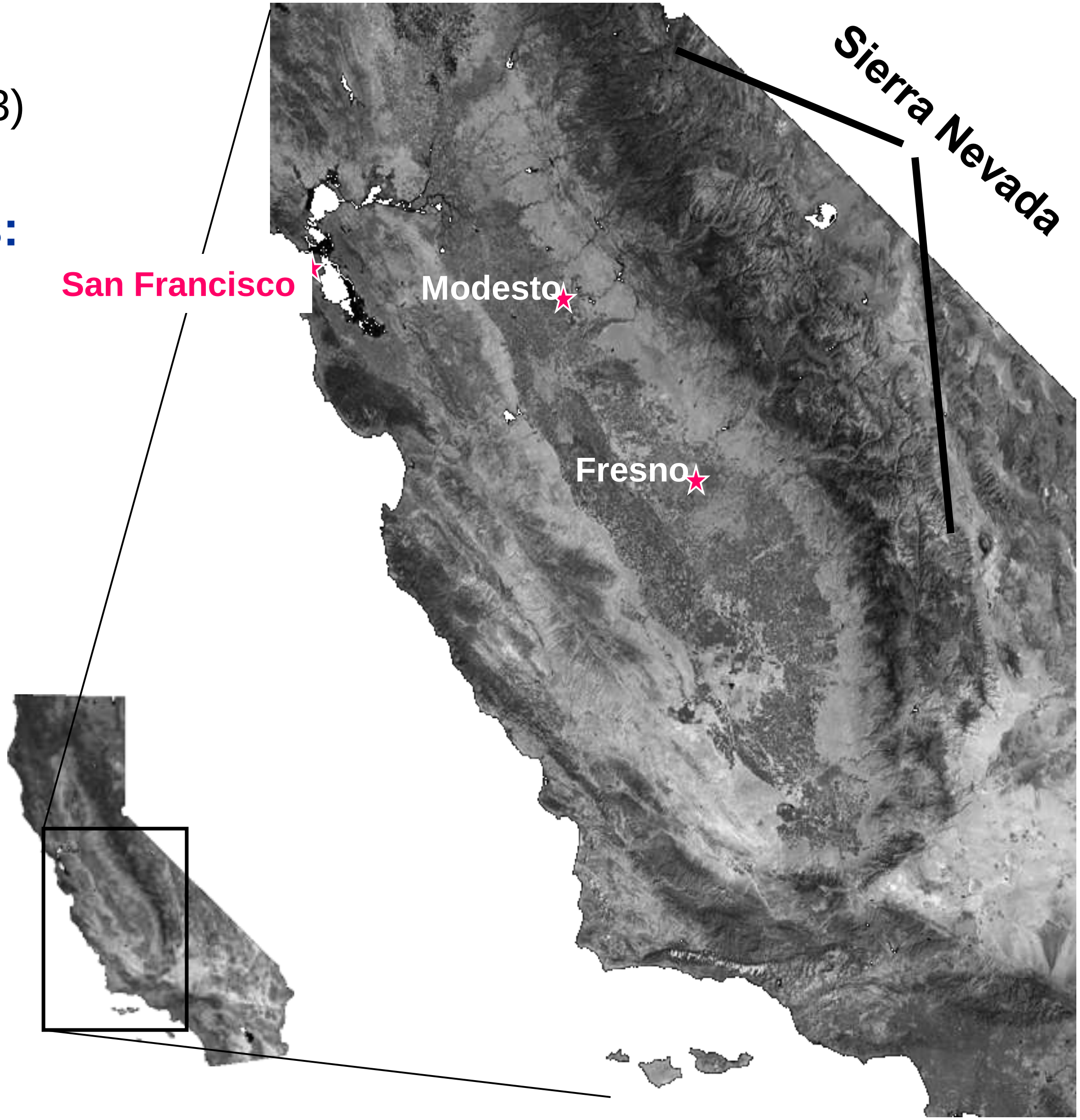
Sarah Norris
Aimee Kneisel

Funding Sources:

NSF (UC Davis)
ACS-Petroleum
Research Fund
US Geological Survey
USDA

Collaborators:

Karen Burow (USGS)
Steve Phillips (USGS)
Graham Fogg
Yong Zhang

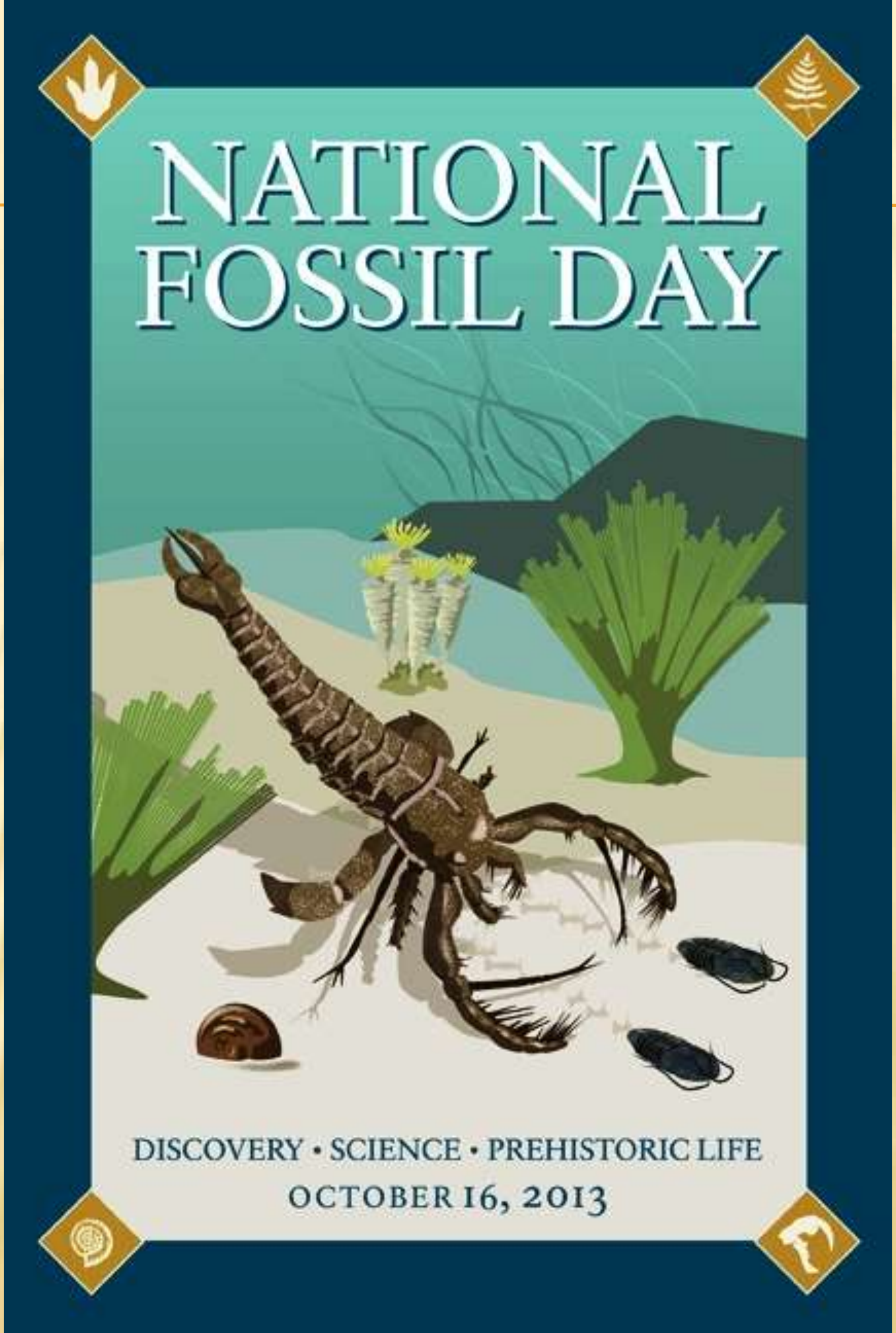



Thank You

CALTRANS PALEONTOLOGY POLICY

Kim Christmann

October 16, 2013


NATIONAL
FOSSIL DAY
DISCOVERY • SCIENCE • PREHISTORIC LIFE
OCTOBER 16, 2013

INFORMATION LINKS

- http://www.earthsciweek.org
- https://www.facebook.com/NatlFossilDay
- http://nature.nps.gov/geology/nationalfossilday

CALTRANS PALEONTOLOGY POLICY

- Why was a policy needed?
- Process Caltrans developed
- Challenges we face
- What do we find?

WHY?

- Legal Requirements
- No legally defined process
- Poorly understood resource
- Lack of advocacy


PALEONTOLOGY

CEQA APPENDIX G

California
Environmental
Quality
Act

V. CULTURAL RESOURCES -- Would the project:

a) Cause a substantial adverse change in the significance of a historical resource as defined in 15064.5?

b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to 15064.5?

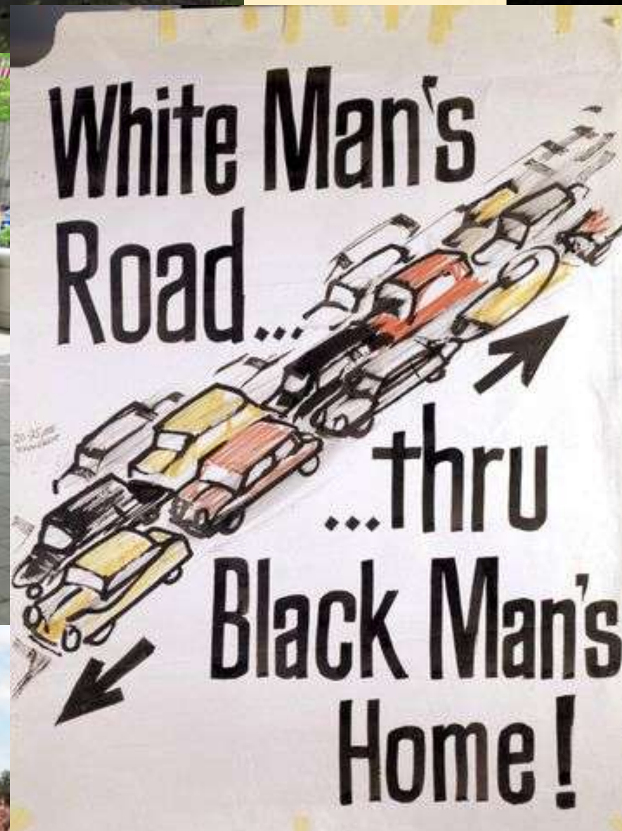
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?

d) Disturb any human remains, including those interred outside of formal cemeteries?


SAVE OUR TREES
BUILD YOUR ROUNDABOUT IN THE FIELD


PROTECT &
PRESERVE
INDIGENOUS PEOPLE'S
SACRED AND BURIAL SITES
NOT 4 SALE


SAVE THE FROGS! DAY


White Man's Road...
...thru Black Man's Home!


CLEAN AIR
STOP THE TOXICS
OUR KIDS DESERVE CLEAN AIR


SHAME BOB SHAME
TELL LABOR... NO MORE
MONASH F'WY
NOISE
TELL LABOR... NO MORE
MONASH F'WY
NOISE


94% DEMOLITION
PRESERVE the VILLAGE'S HISTORY
PRESERVE NYC'S HISTORY

PRIMARY ENVIRONMENTAL LAWS

- CEQA – State
- NEPA - Federal

CEQA

California
Environmental
Quality
Act

- Intent:
  - Maintain and enhance the environmental quality of the state.
- Requires that we determine and take action if:
  - The project would directly or indirectly destroy a unique paleontological resource or site or unique geologic feature
- Applies
  - Whenever a project involves a discretionary action by a State or local agency.

ADDITIONAL STATE LAWS & REGS

- California Coastal Act
- Public Resources Code Section 5097.5
- Title 14 Sections 4307 & 4309

NEPA

- Intent:
  - Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice
- Applies if there is a federal nexus:
  - Federal funding
  - Located on federal property
  - Requires federal approval

ADDITIONAL FEDERAL LAWS & REGS

- Limitation on Federal Participation (23 USC 1.9)
- Federal Aid Highway Act
- National Registry of Natural Landmarks
- Antiquities Act of 1906
- Paleontological Resources Preservation Act

CHALLENGES OF THE LEGAL FRAMEWORK

- Applicable laws must be determined for each project
- Lack of process specifics in the law
- Agencies with jurisdiction must be determined for each project
- Varying agency requirements

PROCESS FOR RESOURCE CONSIDERATION

- Not defined in law
- Used examples and guidance from:
  - Federal agencies
  - Local agencies
  - Museums
  - Private organizations

FEDERAL AGENCIES

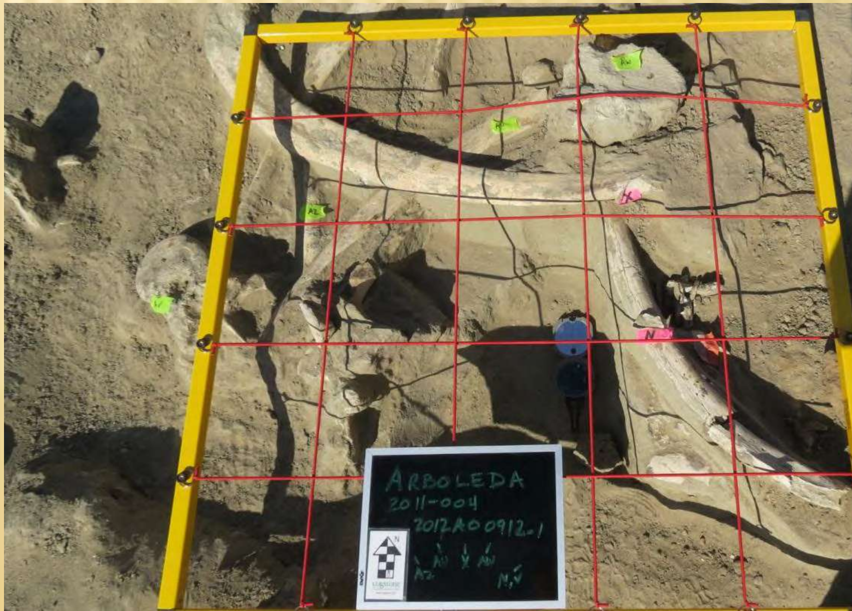
- **Bureau of Land Management**
- **National Park Service**
- Bureau of Indian Affairs
- Federal Highway Administration
- US Forest Service
- US Army Corps of Engineers

STATE AGENCIES

- Ca Dept of Parks & Recreation
- Ca Coastal Commission

OTHER RESOURCES

- Local Agencies
  - San Diego County
- Private Organizations
  - Society for Vertebrate Paleontology
- Museums
  - San Bernardino County
  - UC Berkeley



PROCESS

- Identification
- Evaluation
- Response

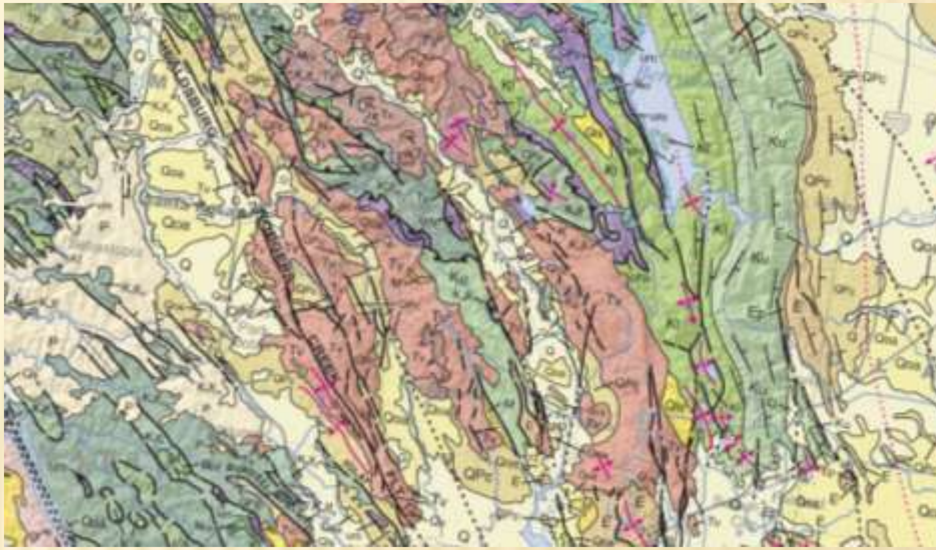
IDENTIFICATION

- Are there potentially fossiliferous formations/deposits present in the project area?

- Will the project include excavation into previously undisturbed deposits?

IDENTIFICATION ACTIVITIES

- Review
  - Geologic maps
  - Literature specifically for
    - Stratigraphy
    - Structural Geology
    - Fossil occurrence
- Field Visit
- Prepare Paleontological Identification Report
  - Recommendation regarding need for evaluation
  - Supports the environmental document



EVALUATION

- Must answer:
  - Are the deposits that will be disturbed by the project expected to be scientifically valuable?
  - Are there unique features present that have important public education value?
  - What is the regulatory framework?
- Paleontological Evaluation Report:
  - Recommendation regarding the need for a response
  - Information needed to support the environmental document

WHAT IS THE RESOURCE?

- Potentially fossiliferous formation or deposit not an individual fossil

FORMATIONS HAVE SCIENTIFIC VALUE IF THEY HAVE THE POTENTIAL TO CONTAIN:

- Vertebrate fossils
- Invertebrate and plant fossils and microfossils that will add to our understanding of:
  - Phylogeny
  - Taxonomy
  - Morphology
  - Stratigraphy
  - Paleoclimatology

RESPONSE

- Avoidance
- Minimization
- Mitigation

AVOIDANCE

- Redesigning the project to completely avoid fossilferous formations.
- Usually not practicable because of the extent of formations.
- May be applied to preserve a unique feature.

MINIMIZATION

- Redesigning the project to reduce the volume of fossiliferous material impacted.
- Also difficult to implement because of the extent of formations.
- But may be implemented to minimize the impact to a unique feature.

MITIGATION

- Paleontological Mitigation Plan
  - Monitoring during excavation activities
  - Fossil salvage
  - Fossil preparation to the point of identification
  - Fossil cataloguing
  - Curation
- Paleontological Mitigation Report

POLICY & PROCESSES

- Caltrans Standard Environmental Reference (SER)
- Under revision
- Interested in reviewing contact:

Kim.D.Christmann@dot.ca.gov

What Do We Find . . .

STATE ROUTE 133

--10 cm--

Fragment of a Baleen Whale Jaw

Whale
Vertebrae

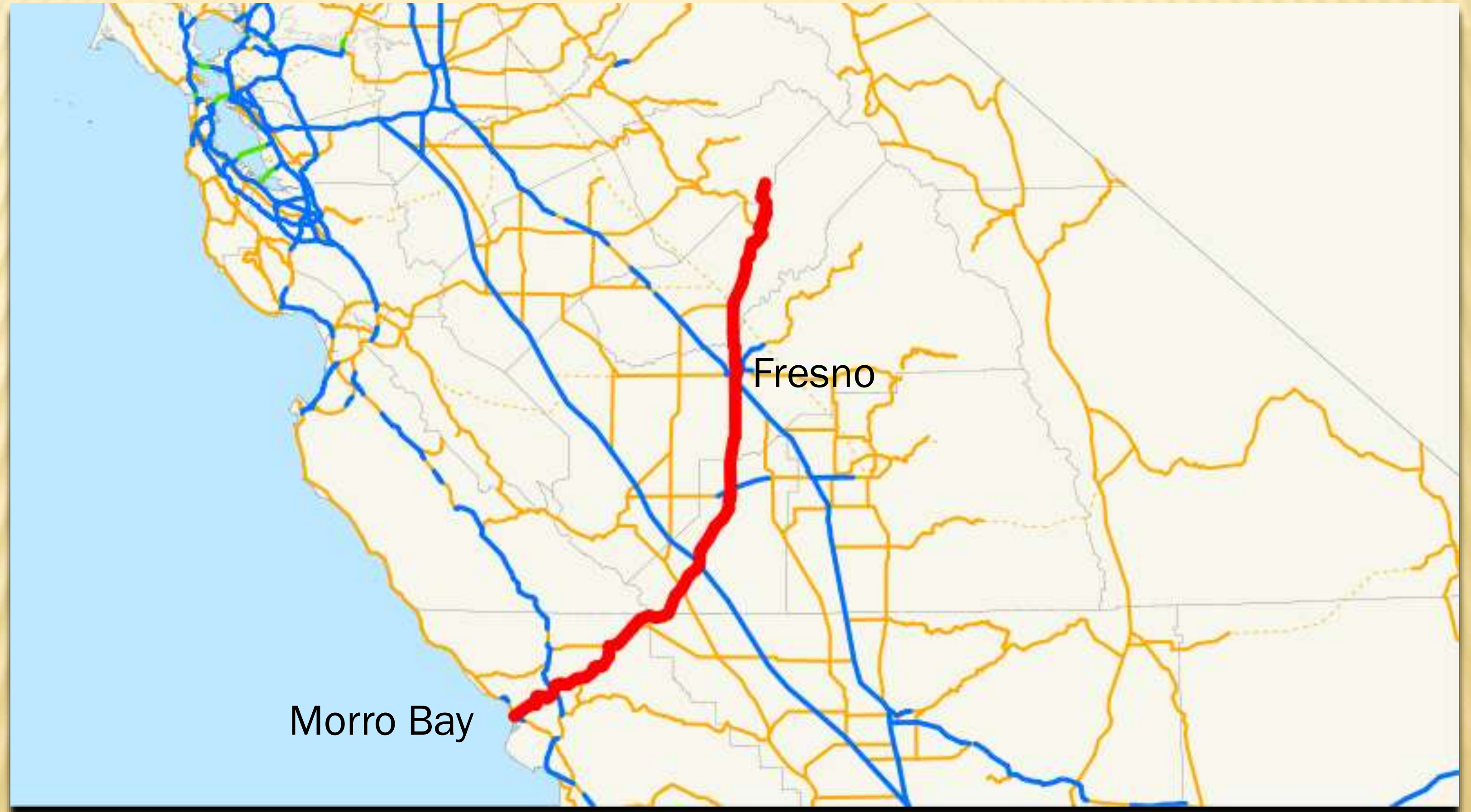
Squalodont – extinct whale with serrated teeth like a shark

Platanistid – type of dolphin

Dorsal

Ventral

STATE ROUTE 41



Pinniped (Seal) collected in 2004

Pinniped Maxillary Teeth

CALDECOTT TUNNEL

130-ton Wirth roadheader used to drill the Caldecott 4th bore:

Camel Vertebrae

Leaves

Horse Metatarsal

Forams

Oreodont Jaw

Clam

STATE ROUTE 76

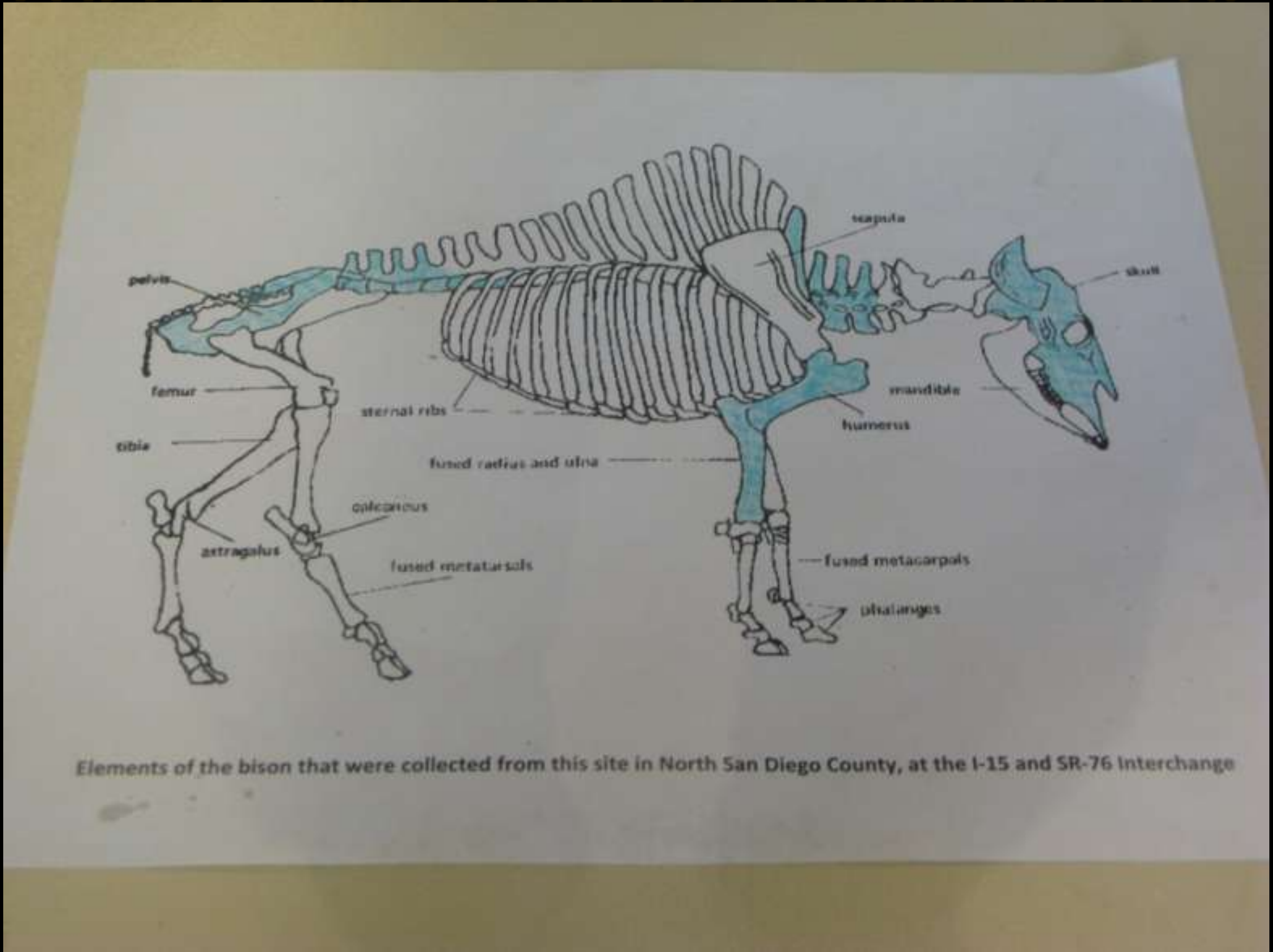
First Pleistocene bison ever found in San Diego County - Spring 2013


Welcome to the Mr. and Mrs. Bruce Hazard
Research Demonstration Lab
A window into research and collections at theNAT
There is more to the museum than exhibits.
We have a collection of more than 7.4 million
specimens–fossils, plants, insects, reptiles,
birds, mammals,
Most of our collections are from Southern
California and the Baja California peninsula.
At theNAT, our mission is to better understand
the plants, animals, and geology
PALACE OF

GOOGLE: YOUTUBE CALTRANS BISON

- http://www.youtube.com/watch?v=_n2XPmCKclo

FOSSILS COLLECTED SHOWN IN BLUE



BISON – FOSSIL PREPARATION COMPLETE

PELVIS & RIBS

HUMERUS AND RADIUS & ULNA

STATE ROUTE 99 IN MADERA

New Species of Dire Wolf
(cranium on the right and
humerus on the left)

Camel and extinct Horse

STATE ROUTE 99 IN MERCED

Western Horse Tooth

Western Horse

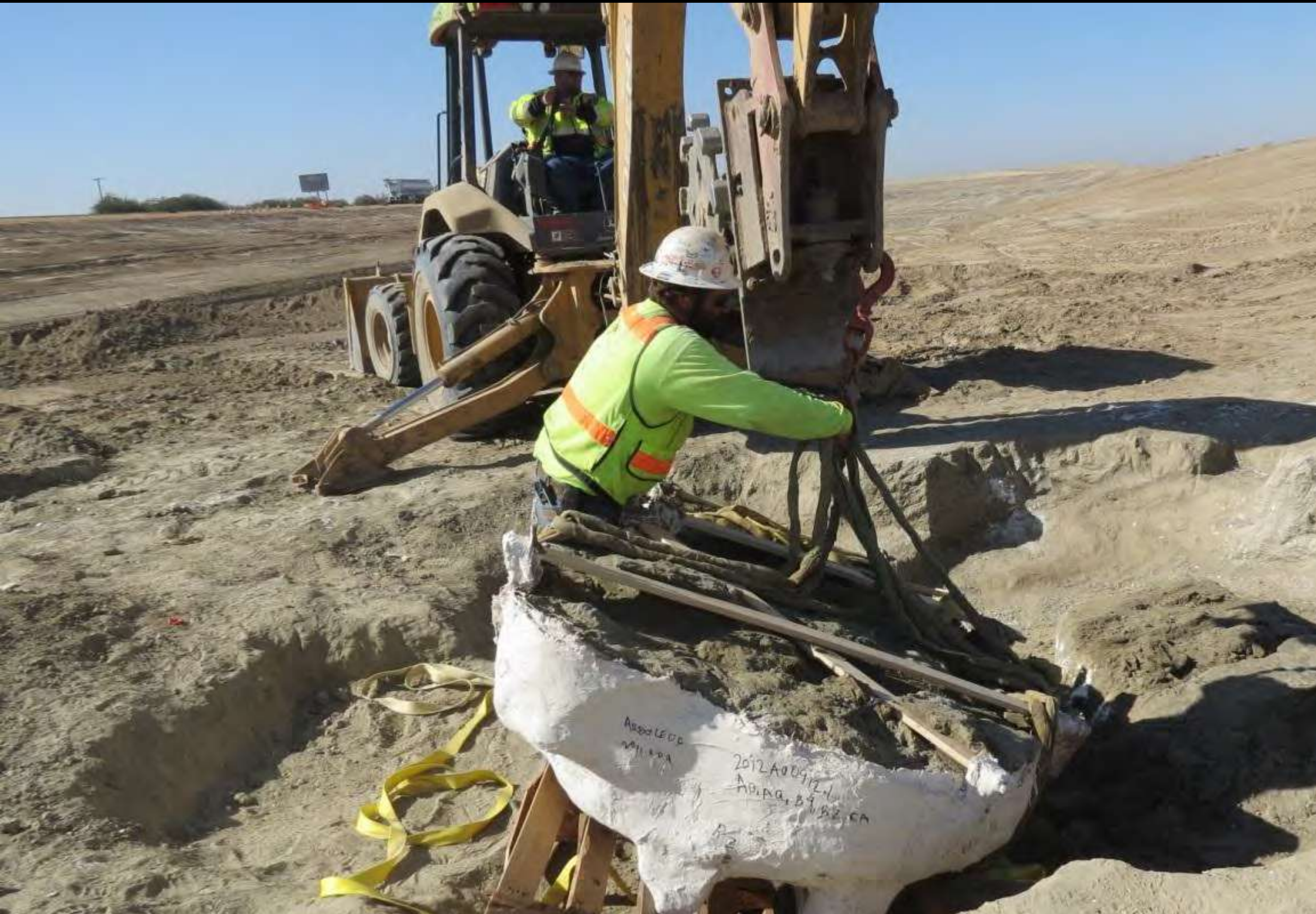
Columbian Mammoth – ribs & vertebrae

Columbian Mammoth – skull and tusks


DEER


DEERE


DEERE




DEERE


TJF 4030


DEERE
TJF 4030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