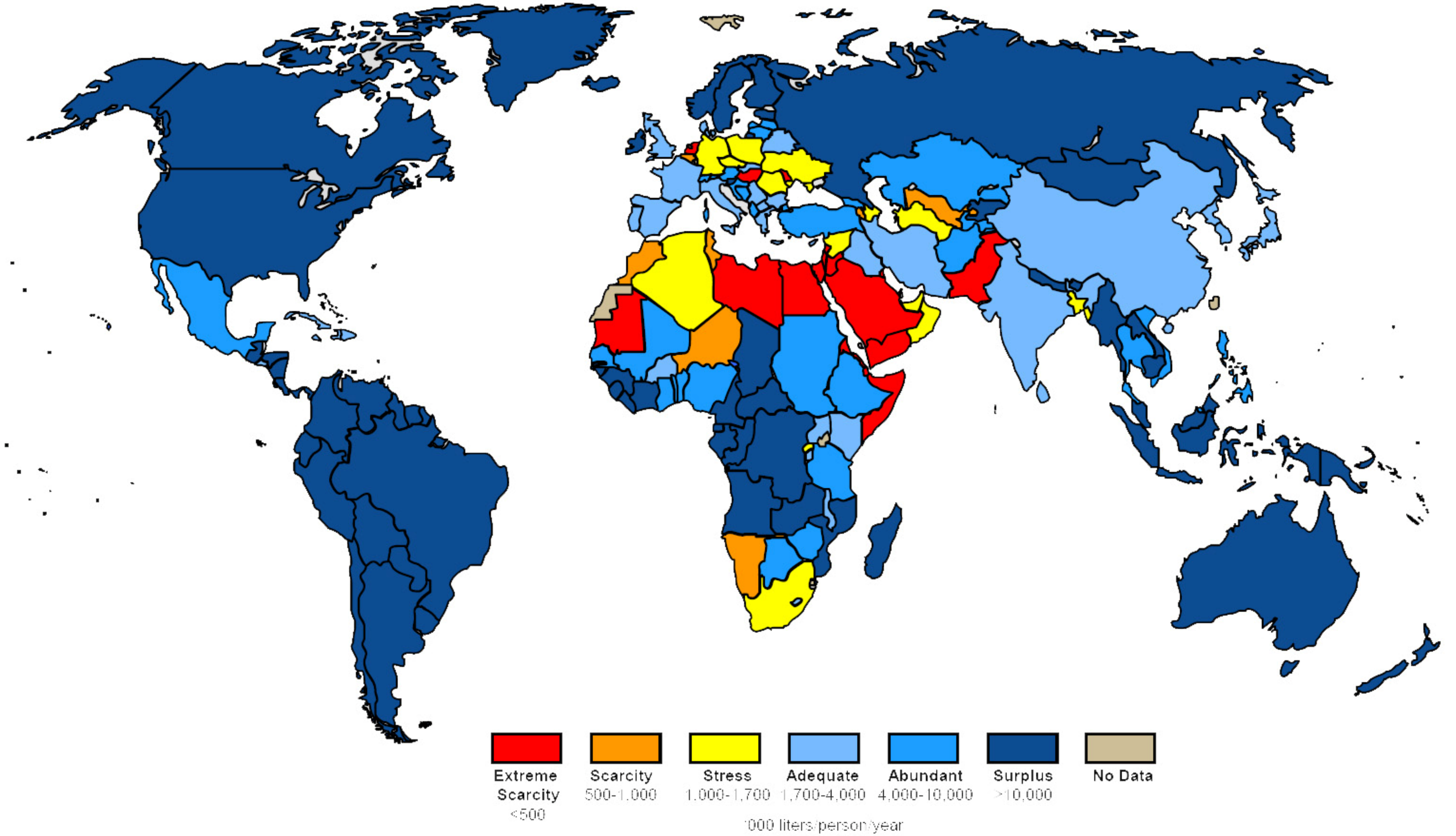
Aguas subterráneas envenenadas

Marinus Eric Donselaar - Delft Univ. of Technology

UN Human Rights Council on water

- *Access to safe water is a fundamental human need and therefore a basic human right* (Kofi Annan)
- Human Rights Council resolution (Sept. 2010):
- Right to water and sanitation are part of existing international law
- Rights are legally binding upon States
- http://www.righttowater.info/international-timeline/#sep2010

Global Per Capita Water Availability (1975)



Source: 'Global Water Initiative' (June 2005), GEF International Waters Conference, The Coca-Cola Company

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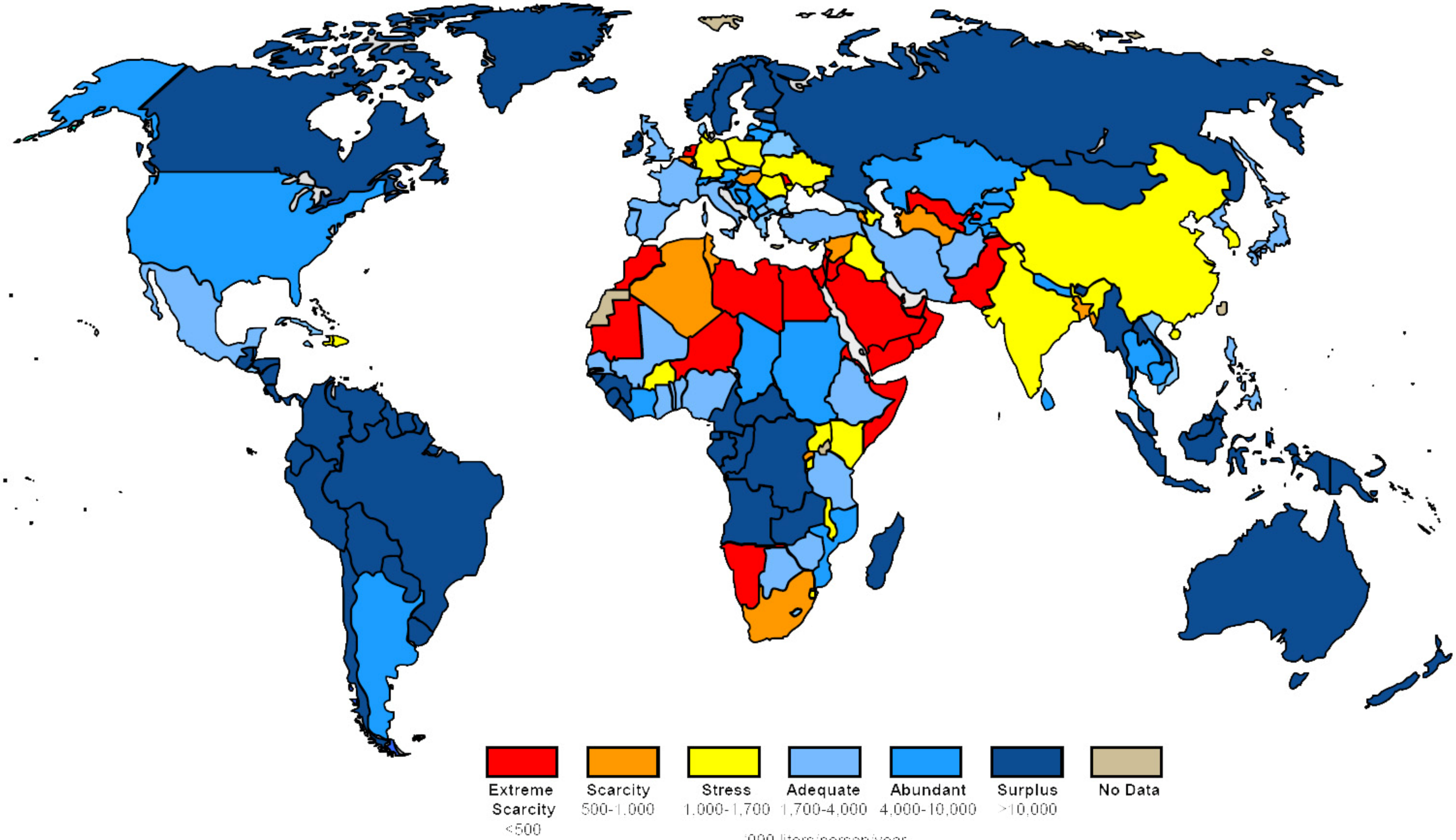
http://www.grailresearch.com/pdf/ContenPodsPdf/Water-The_India_Story.pdf

Global Per Capita Water Availability (2000)



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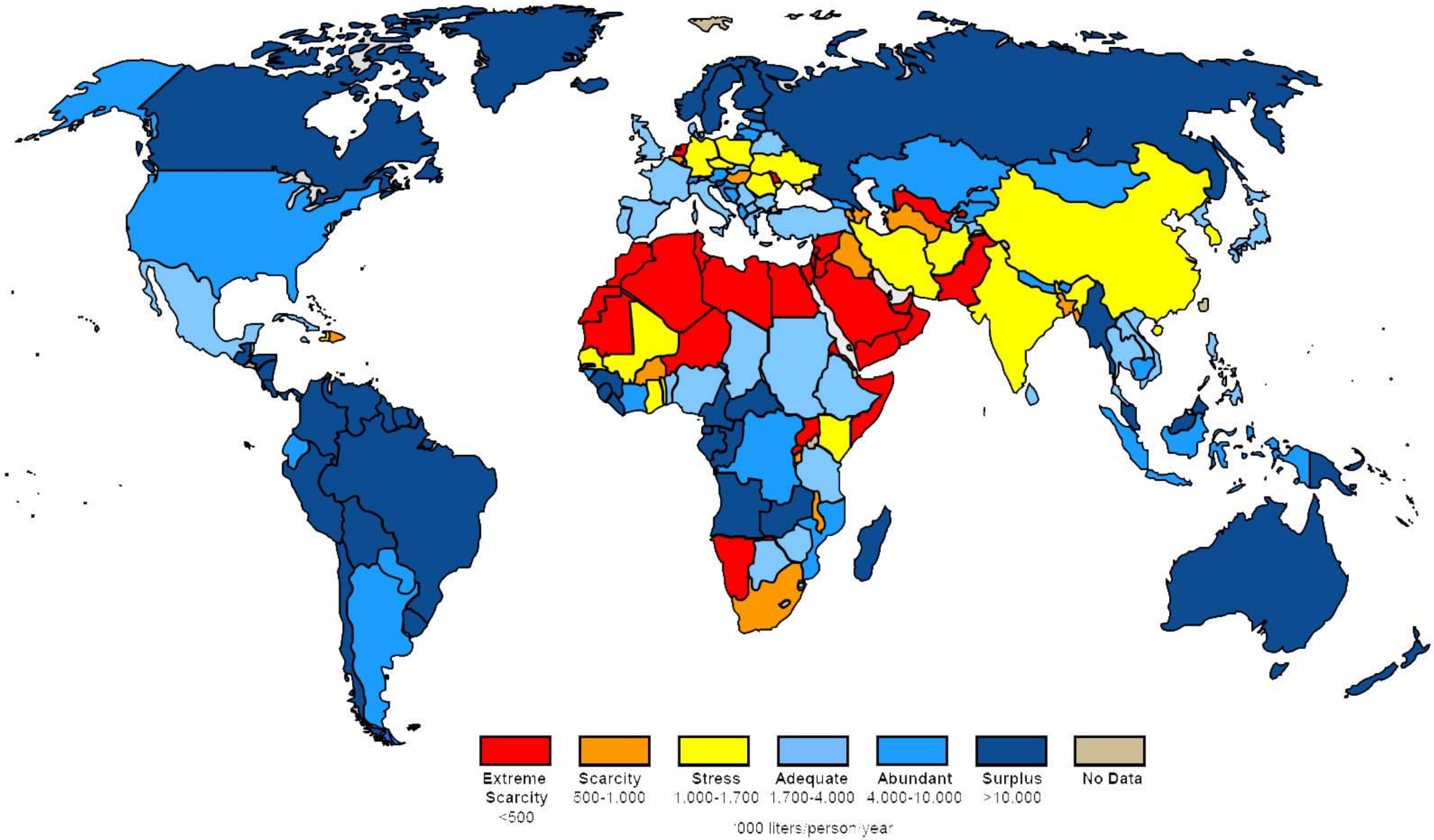
Global Per Capita Water Availability (2025)



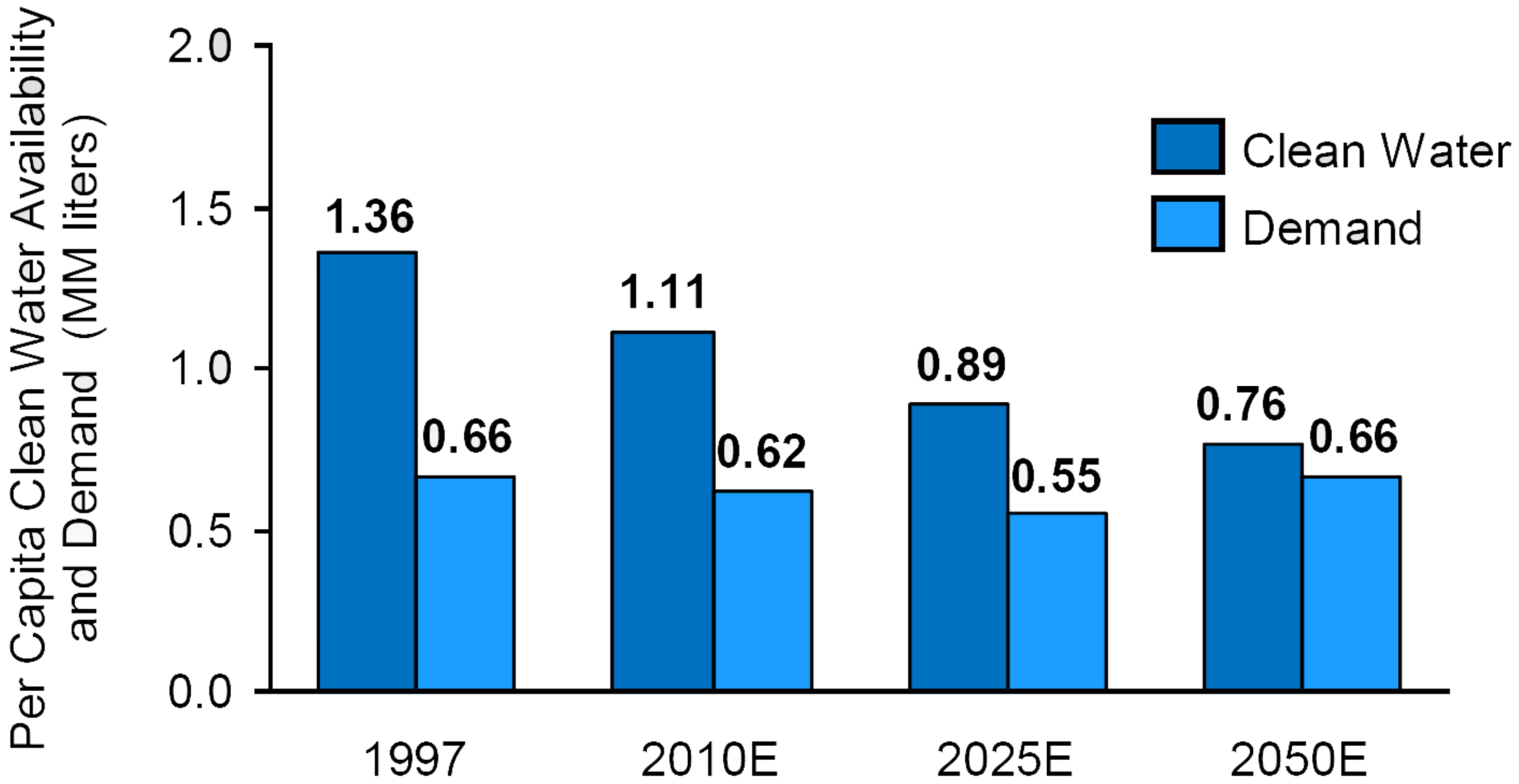
Source: 'Global Water Initiative' (June 2005), GEF International Waters Conference, The Coca-Cola Company

http://www.grailresearch.com/pdf/ContenPodsPdf/Water-The_India_Story.pdf

Reasons for increase in water scarcity

- International conflicts
- Population growth → urbanization
- Increase prosperity third-world countries
- Increase in industrialization
- Contamination
  - Industrial
  - Agricultural
  - **Natural (geologic origin)**

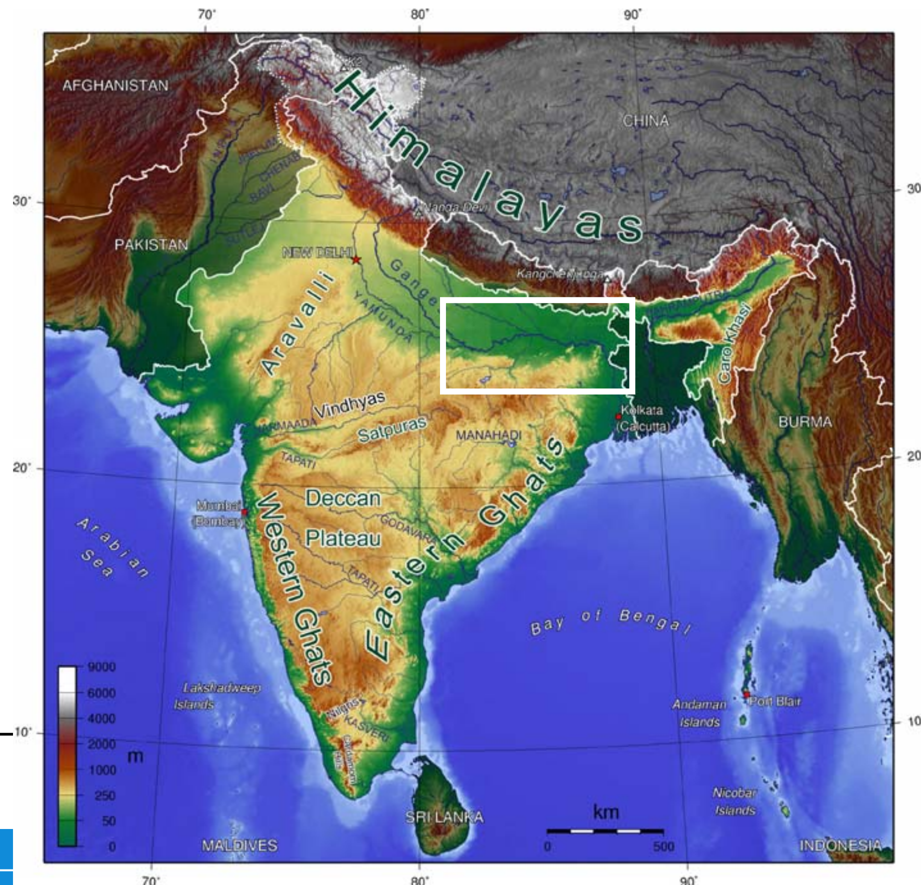
Water availability - India



http://www.grailresearch.com/pdf/ContenPodsPdf/Water-The_India_Story.pdf

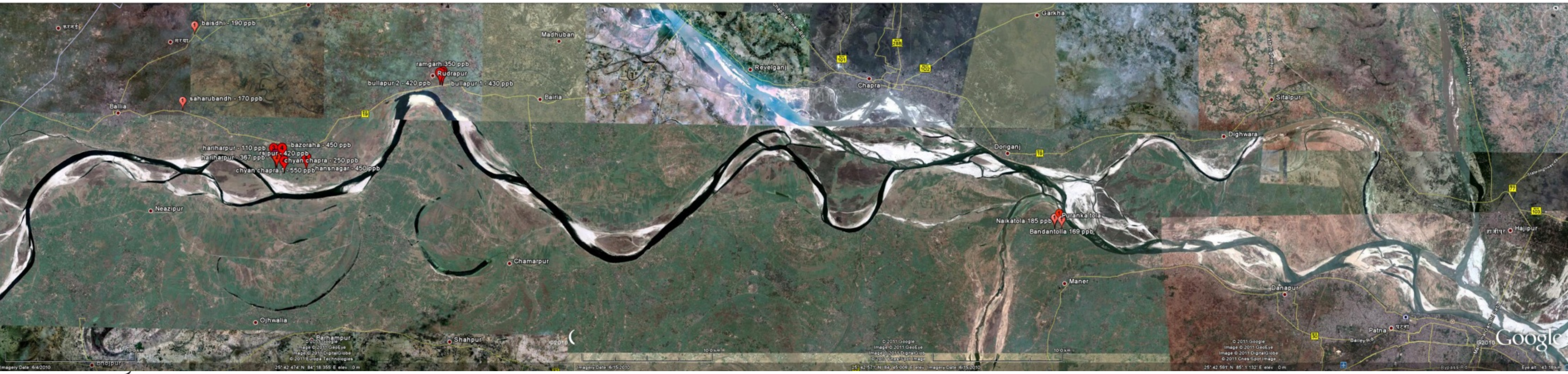
Arsenic contamination in Bihar, India

- Introduction
- Geological origin spatial distribution of arsenic contamination
- Results
- Conclusions
- Future work



Arsenic contamination in Bihar

- First detected in 2002
- Concentrations up to 1800 µg/L (WHO limit: 10 µg/L)
- Groundwater contamination in top ~50 m of Holocene fluvial sediments along Ganges River
- **Strong spatial variation in arsenic concentration**



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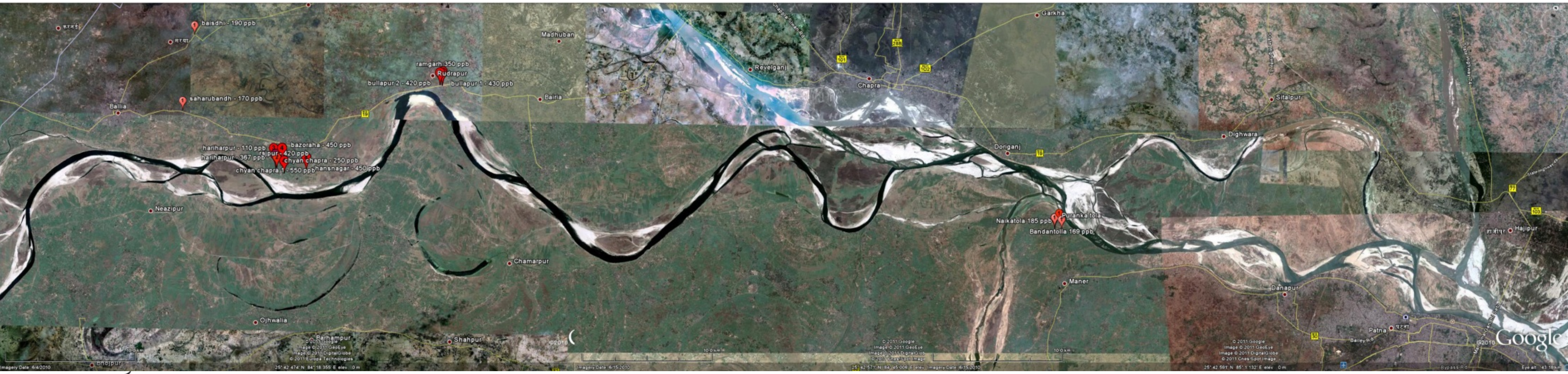
Aims

- Analyze the geological control on arsenic distribution
- Predictive models to locate safe, arsenic-free zones for irrigation and drinking water extraction



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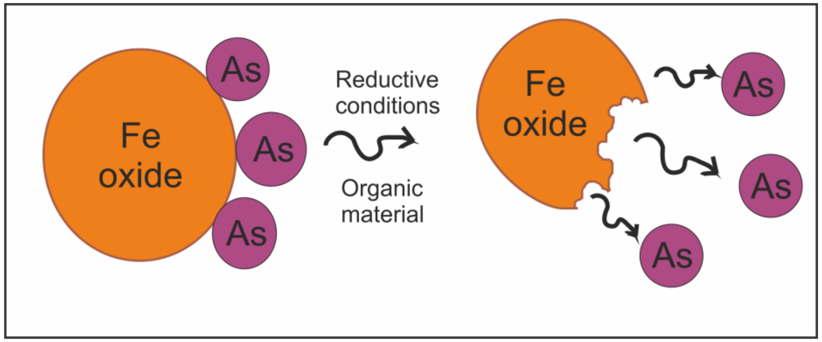
Arsenic worldwide

Arsenic characteristics:

- Arsenic is a naturally occurring compound. It is found in the Earth's crust at a concentration of around 2-5 ppm
- Arsenic is the 20th most abundant element on Earth
- Occurs in:
  - Biotite or Fe-Mn coatings
  - Clay particles or calcite
- Arsenic occurs in natural waters as oxyanions of As III or As V
- About 100 mg of As is lethal - that's 1/20th of a teaspoon

Geogenic origin arsenic contamination

- Arsenic transported in solid phase (Fe-As oxides) by rivers from orogenic provenance to sedimentary basin
- Arsenic released to groundwater in redox-controlled environment:
  - Abundance of organic carbon prerequisite
  - Microbial respiration triggers reductive dissolution Fe and As
  - Arsenic-contaminated aquifers in shallow fluvial, lacustrine and deltaic sediments

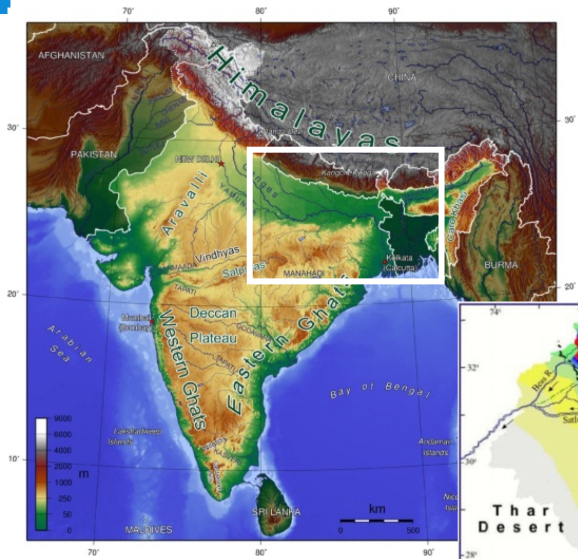


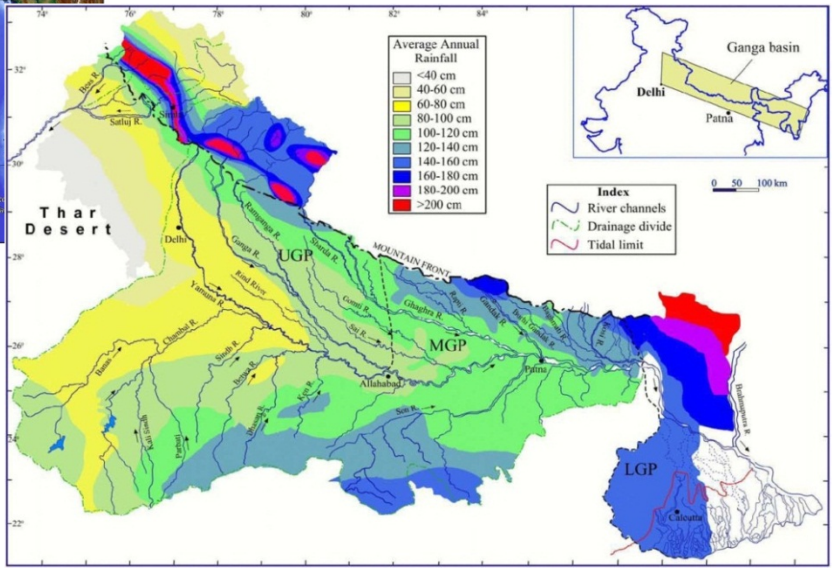
Iron-oxide staining: proxy for As

Hyperkeratosis

Ganges Basin

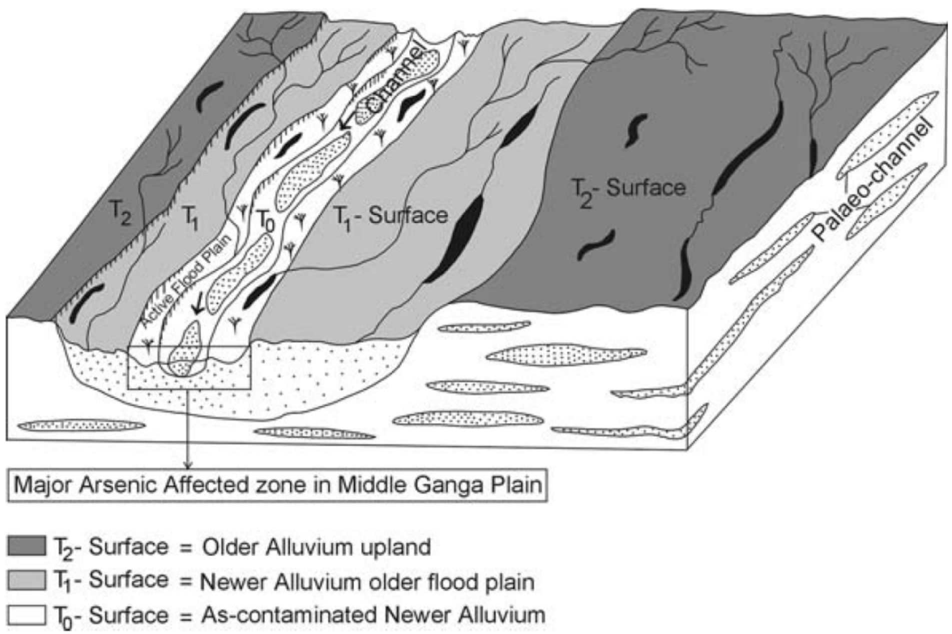
- Provenance: Himalayas
- Multiple source areas
- Fe- and As-containing pegmatites in source area





Sinha et al. (2005)

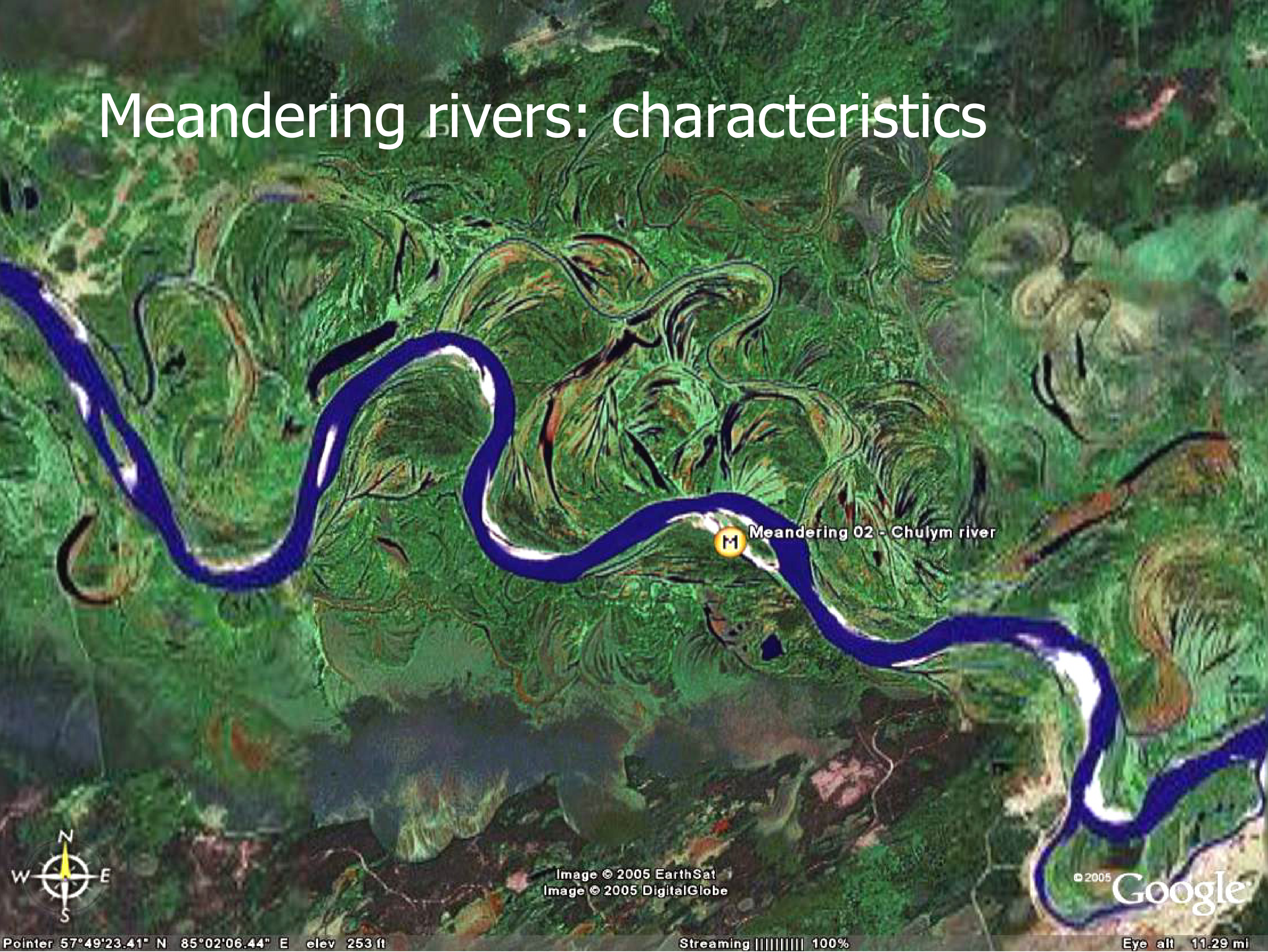
Geological setting



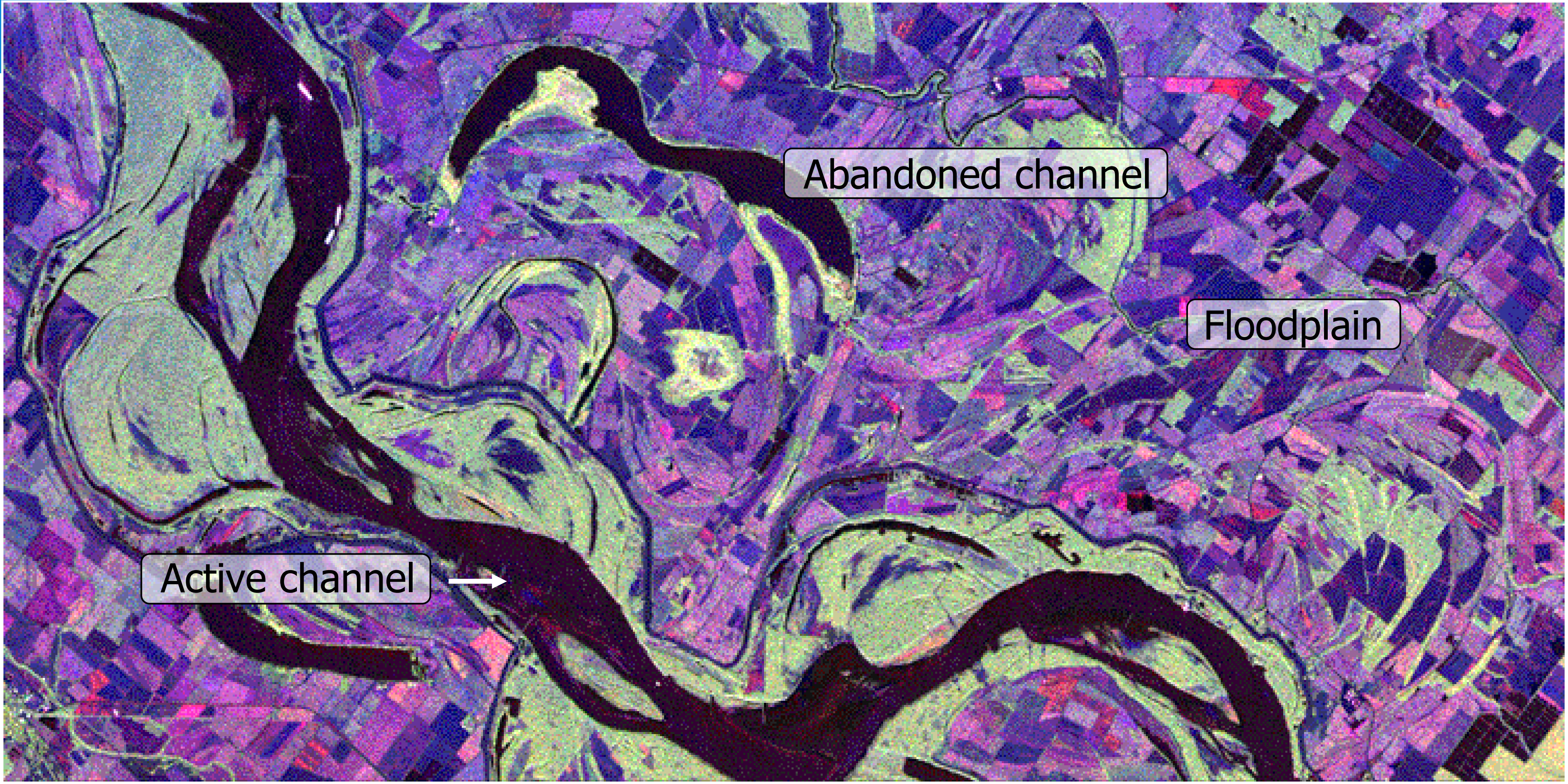
Shah (2008)

- Pleistocene basement:
  - Alluvial fan sand
  - Arsenic-free
- Uplift and valley incision
- Incised-valley fill with Holocene fluvial channel belts:
  - Meandering river sand and mud
  - Arsenic-rich

Meandering rivers: characteristics



Meandering rivers: Sub-environments



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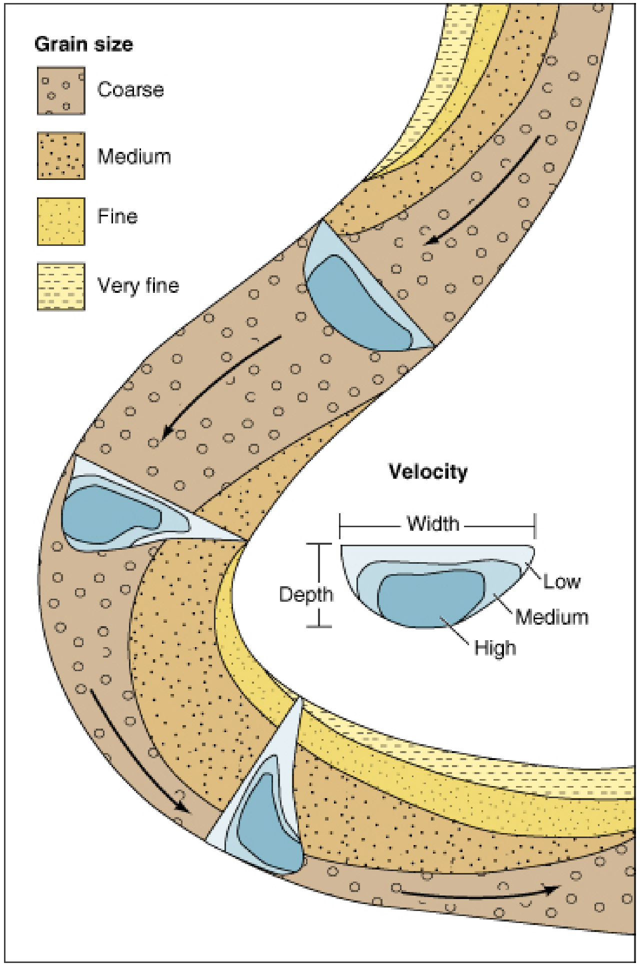
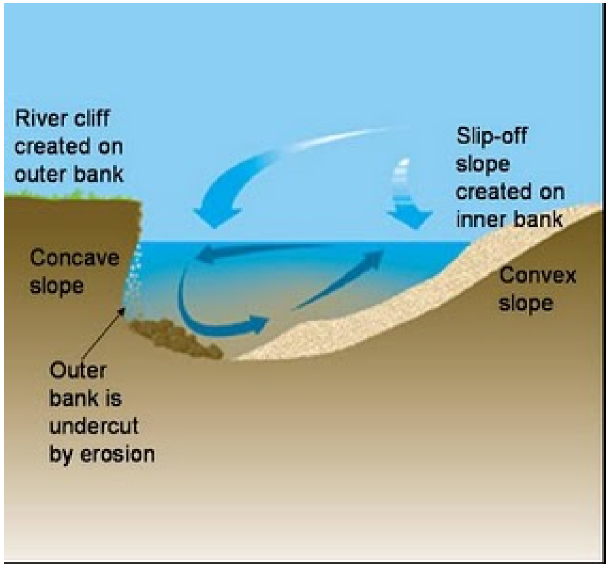
Sediment transport in river

- Sand transported over the channel floor
- Clay and silt in suspension in the water column

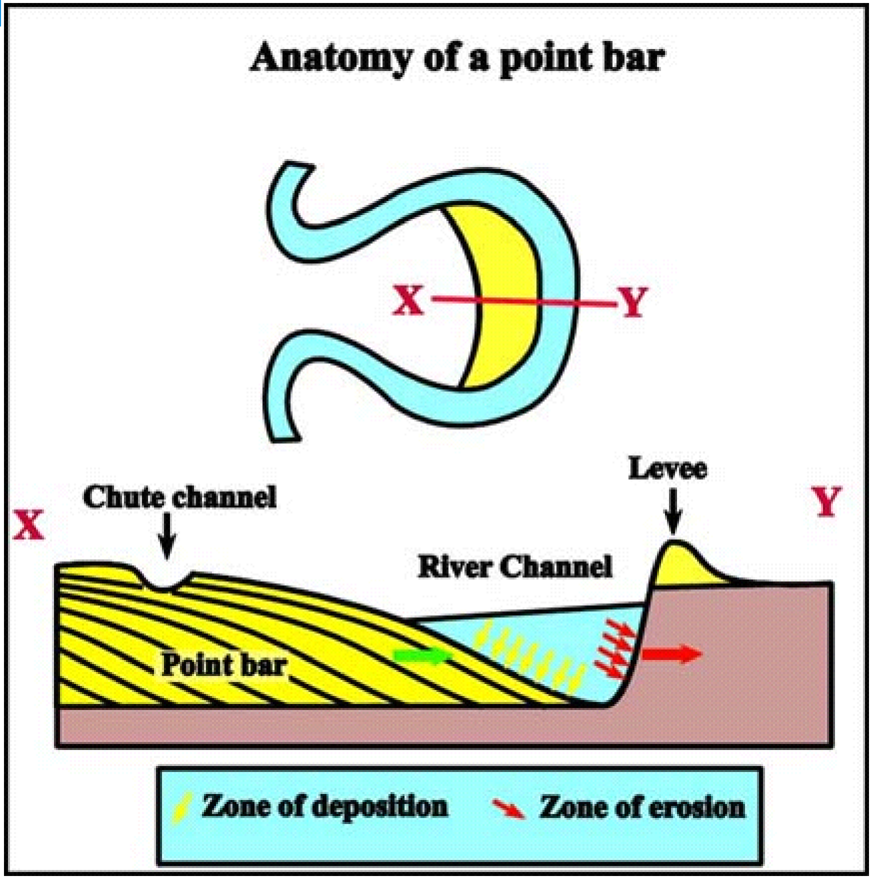
Grain size distribution



- Differentiation of flow velocity leads to:
- Spatial separation of grain sizes



Meandering rivers: *Point bar accretion*



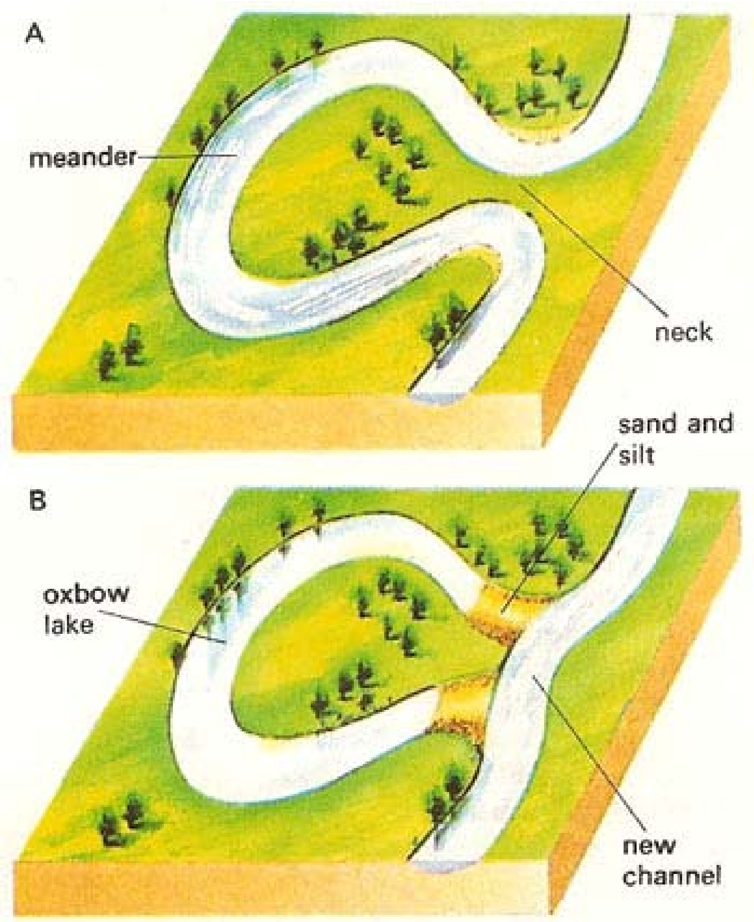
- Differentiation of flow velocity leads to:
- Erosion of outer bank (*cut bank*)
- Deposition of sand on inner bank by lateral accretion (*point bar*)
- Effect: lateral migration of river channel

Sand accumulation in inner bend

http://www.panoramio.com/photo/39211485

- Sand accumulates in inner bends of meandering river
- Half-moon shape

Meander bend cut-off: oxbow lakes



- Cut bank erosion in opposing bends:
- Cut-off of entire meander bend
- Converted to oxbow lake
- Sedimentation out of suspension in flood periods
- Oxbow lake filled with clay, silt: clay plug

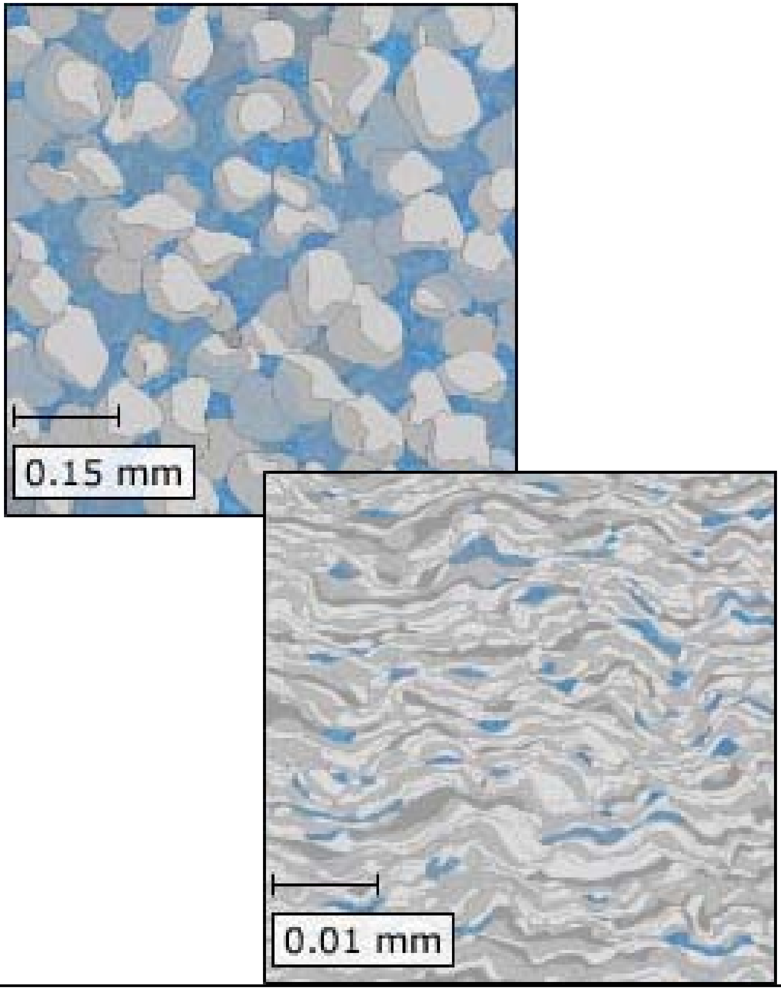
http://www.daviddarling.info/images/oxbow_lake.jpg

Meandering rivers: *Floodplain*

- Only flooded at peak run-off
- Lithology: mainly silt & clay, fine sand: settles out of suspension

http://graphics8.nytimes.com/images/2009/03/31/us/31red_span.jpg

Sand-clay permeability differences

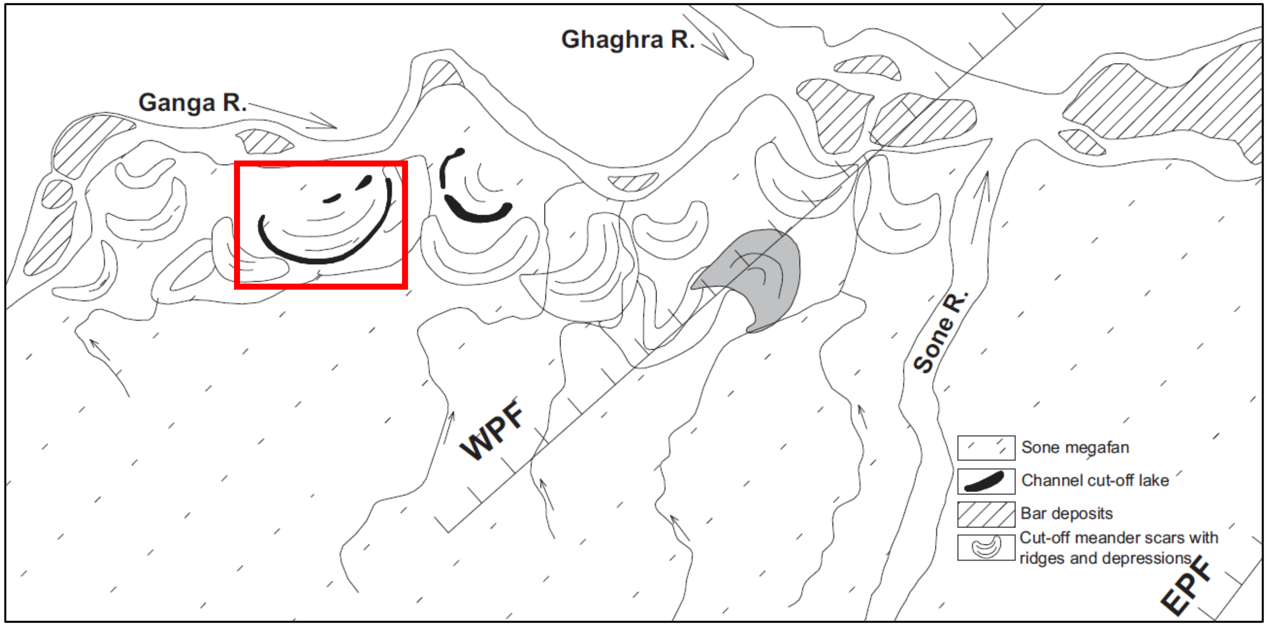


- Sand: spherical grains with ample pore space → high permeability
- Clay: flakes, easily compressible, pore spaces squeezed → low / no permeability

http://www.classzone.com/books/earth_science/terc/content/investigations/es1401/es1401page04.cfm

River migration and sedimentology

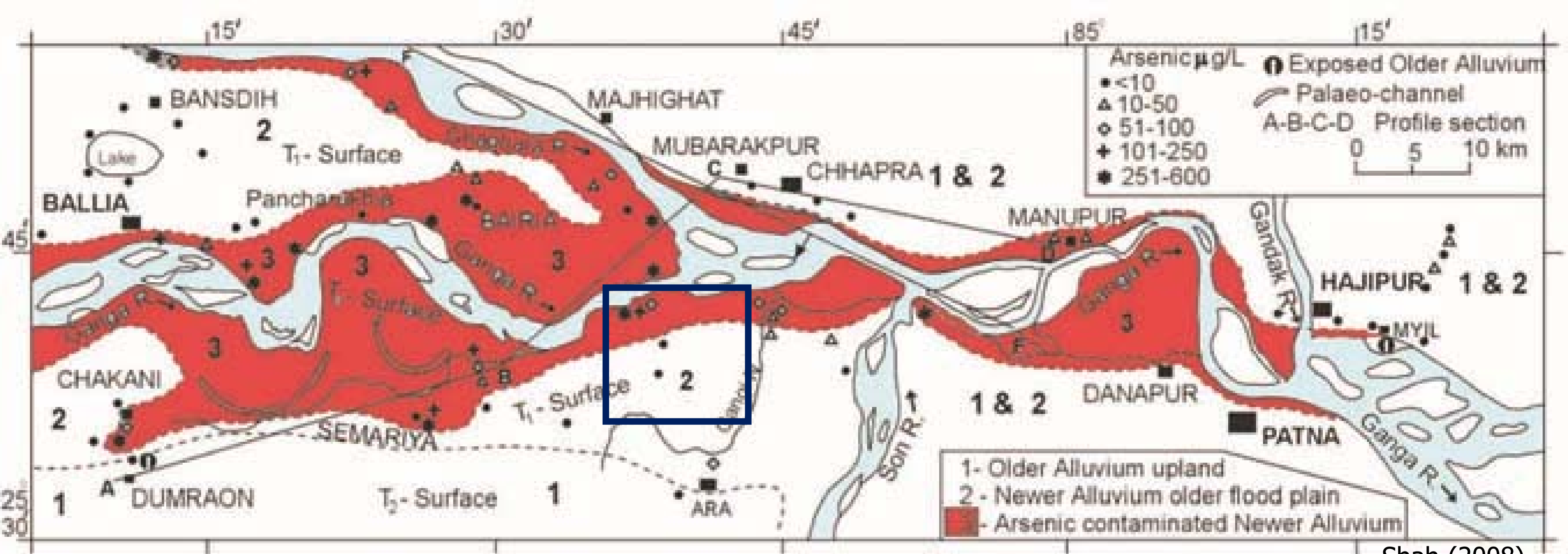
- Upon migration: river point bar sand and clay preserved
- Sand-clay porosity-permeability heterogeneity
- Heterogeneity rules spatial distribution arsenic



Sahu et al. (2010)

Arsenic contamination

- Concentration strongly varies with geographical position
- Arsenic in shallow water wells



Shah (2008)

Abandoned point bar & clay plug

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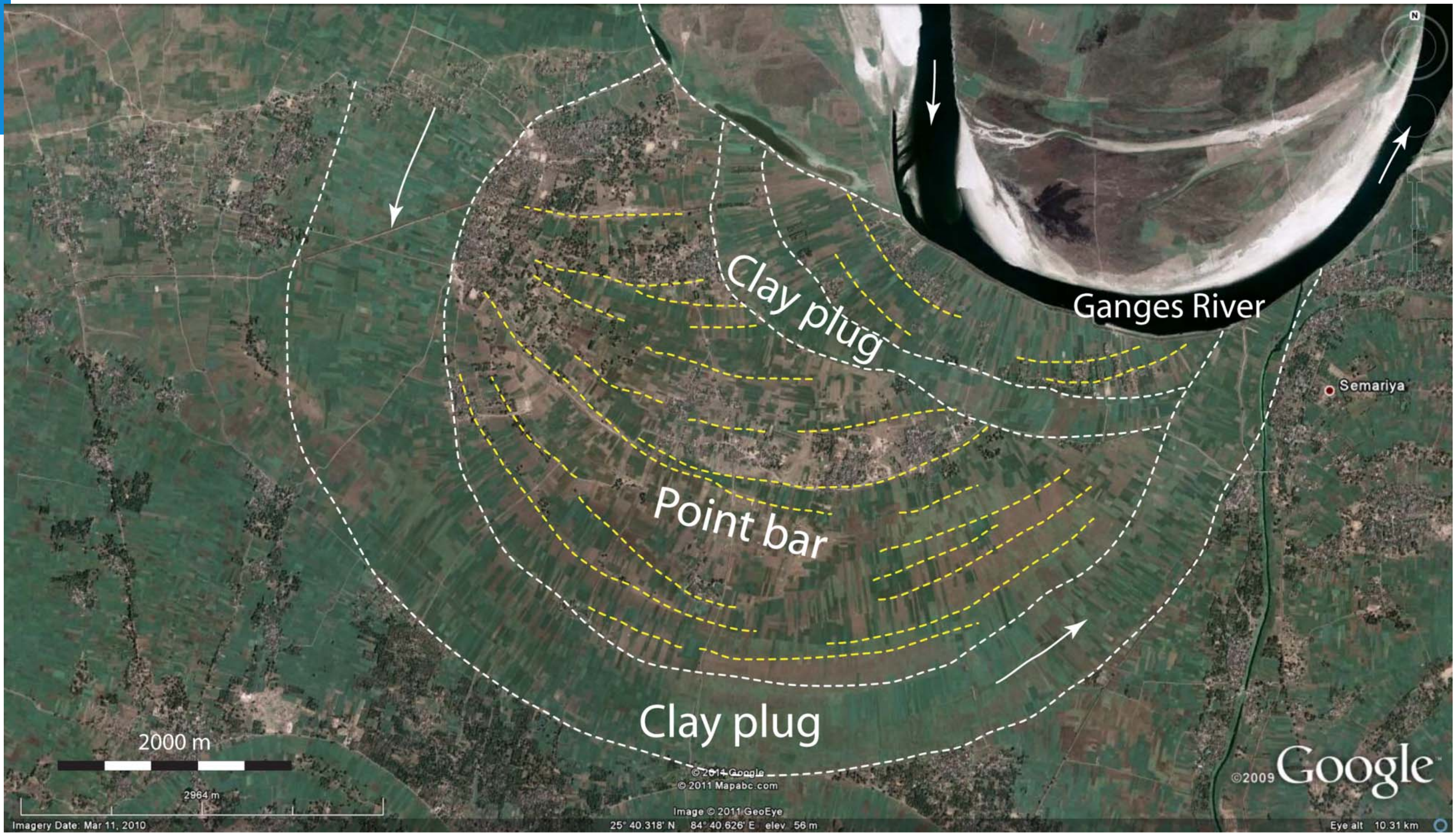
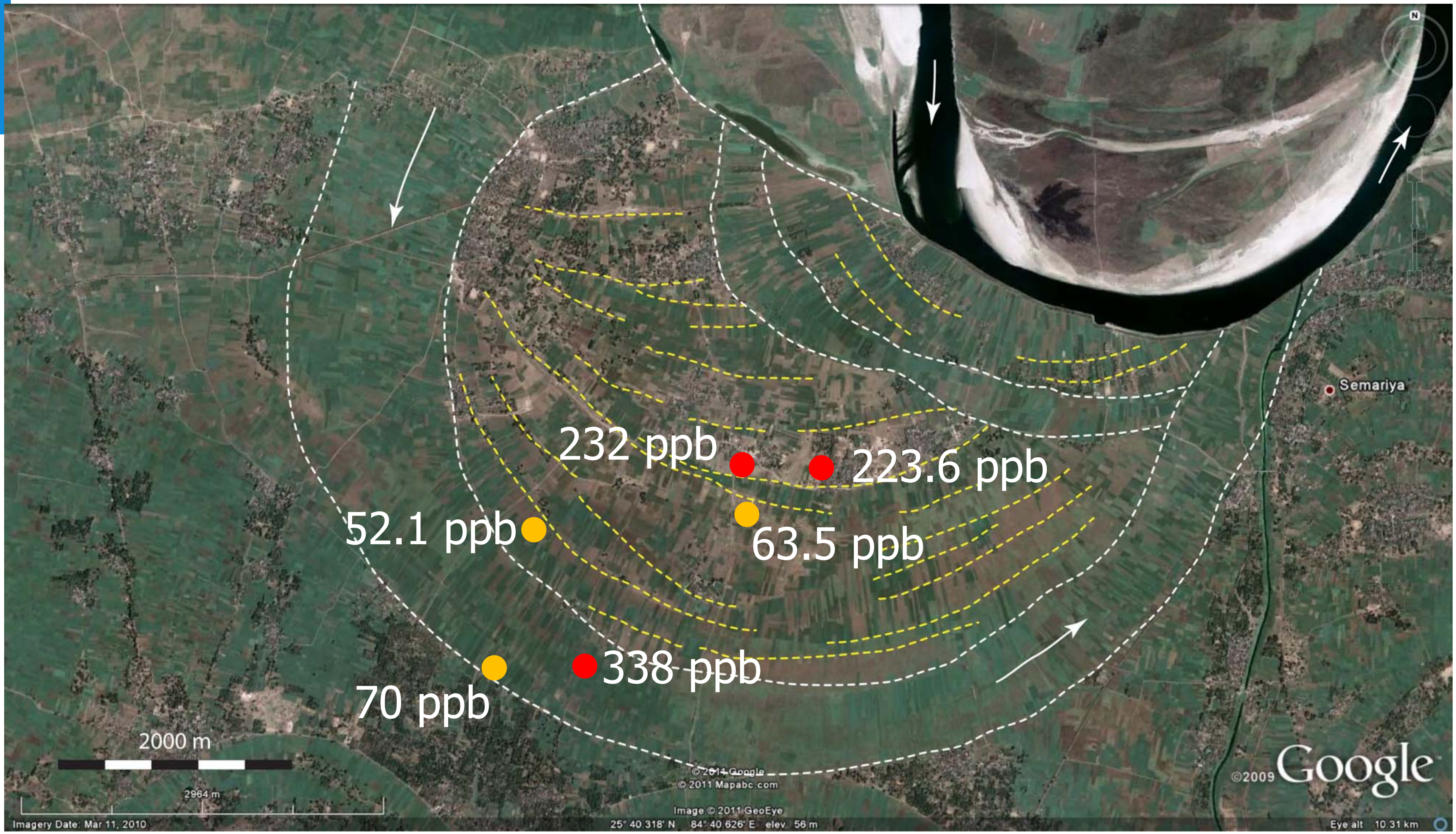
Point bar - clay plug heterogeneity



Arsenic contamination levels



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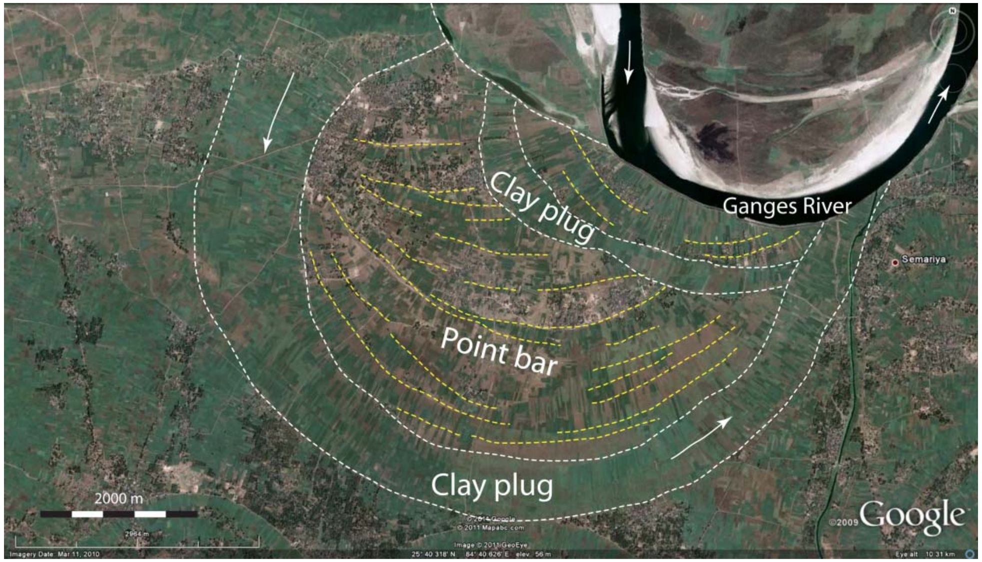
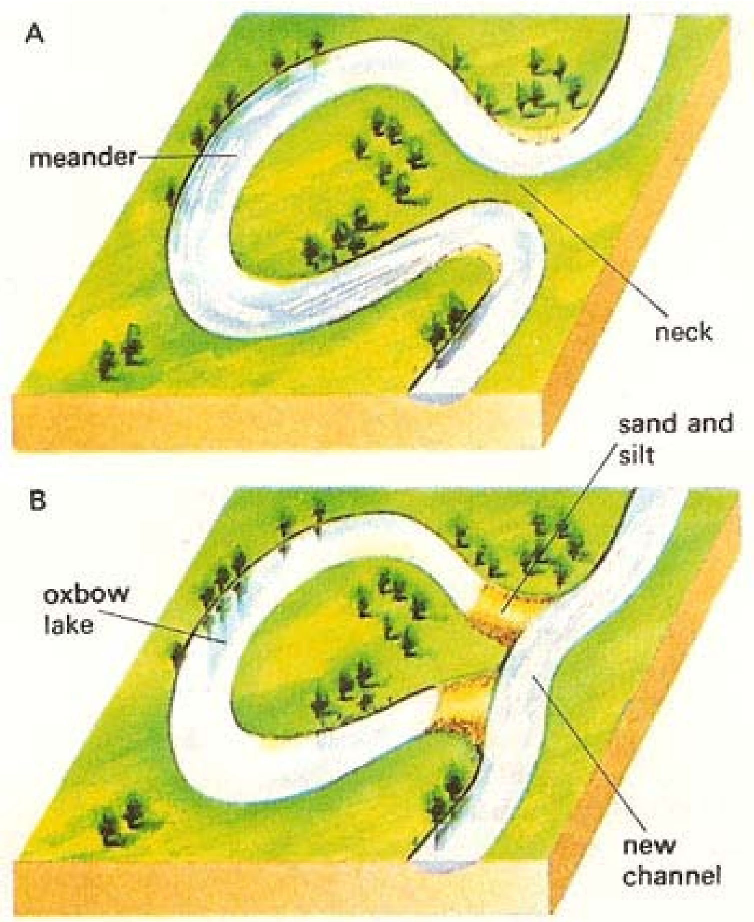
Spatial variation of arsenic contamination



- Point bar consist of inclined alternating layers of sand and clay
- Arsenic-contaminated water in permeable sand layers
- Point bar surrounded with impermeable clay-filled oxbow lakes
- Villages and water wells located on point-bar sand ridges

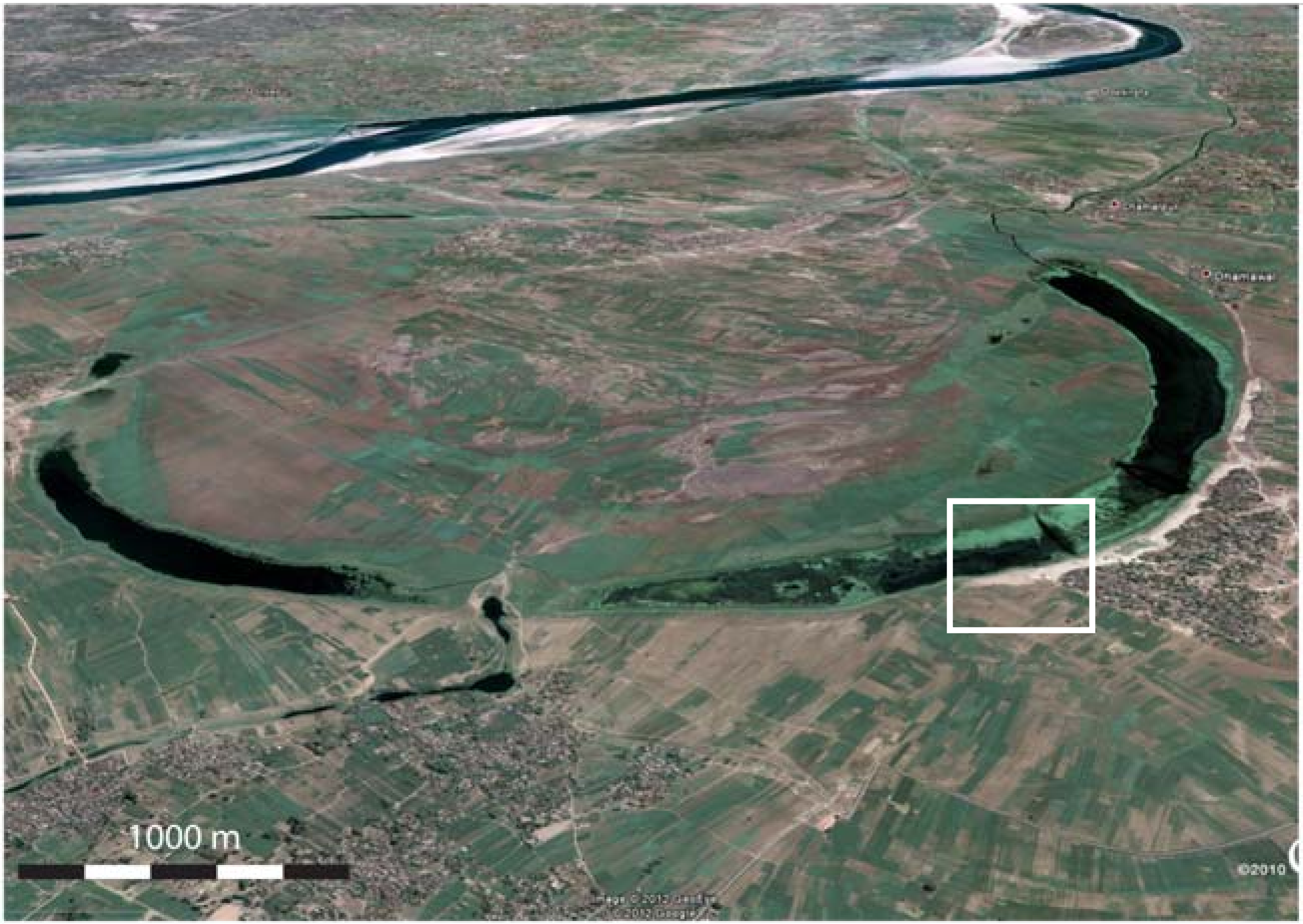
Work hypothesis: Arsenic released adjacent to oxbow lakes



- Cut bank erosion in opposing bends:
- Cut-off of entire meander bend
- Converted to oxbow lake
- Plants and animals live and die in lake
- Oxbow lake locus of organic-rich carbon

http://www.daviddarling.info/images/oxbow_lake.jpg

Partly-filled oxbow lake north of Shahpur



Sedimentation in oxbow lake

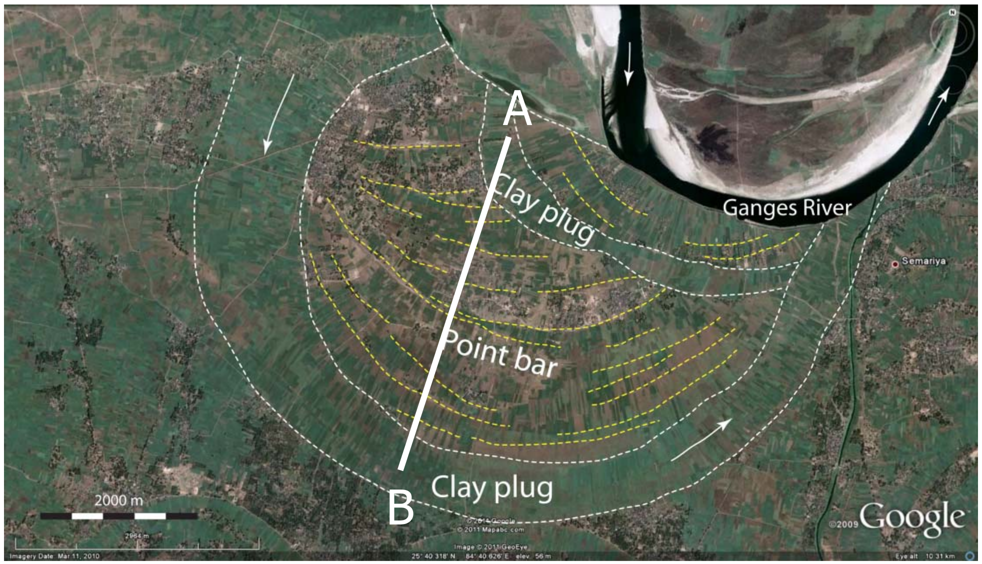
- Plant growth from lake edge → center
- Mud settling out of suspension

Oxbow lake – Point bar

http://www.panoramio.com/photo/39211485

- Clay-filled organic carbon-rich oxbow lake sediment encompasses:
- Permeable point bar sand
- Upon release, arsenic trapped in pore fluid of point bar

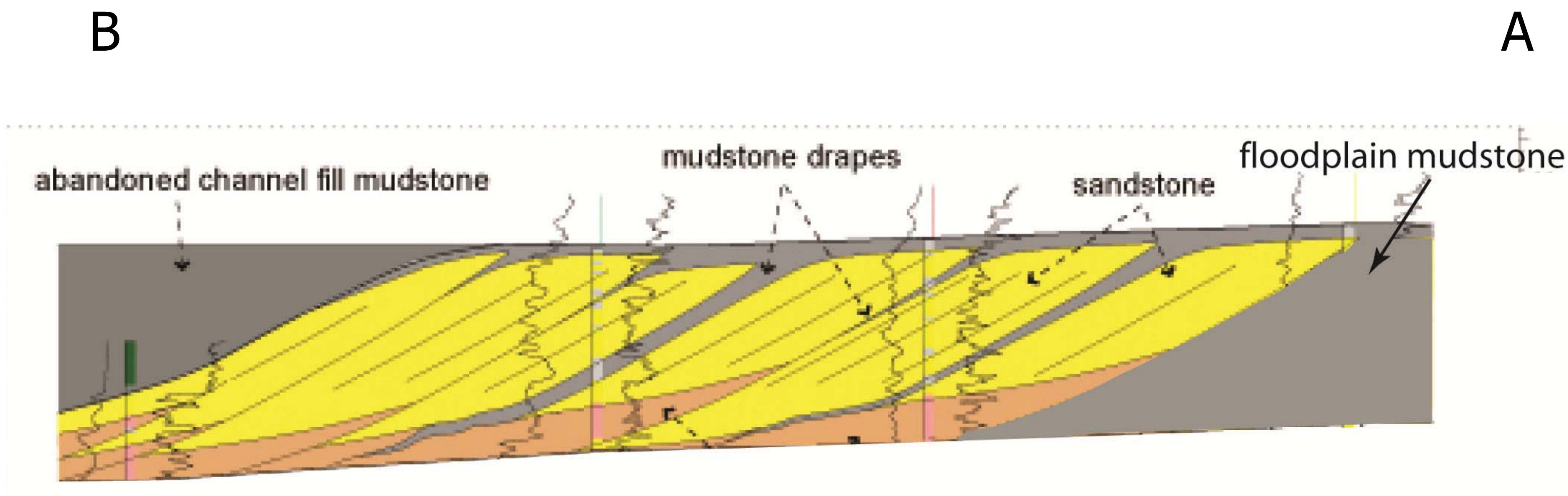
Stratigraphic trap



- Point bar sediment body size:
  - Thickness: ~12 m
  - Area: 16.25 km^2
- Fining-upward succession with clay-draped lateral accretion surfaces
- Surrounded by impermeable clay plug

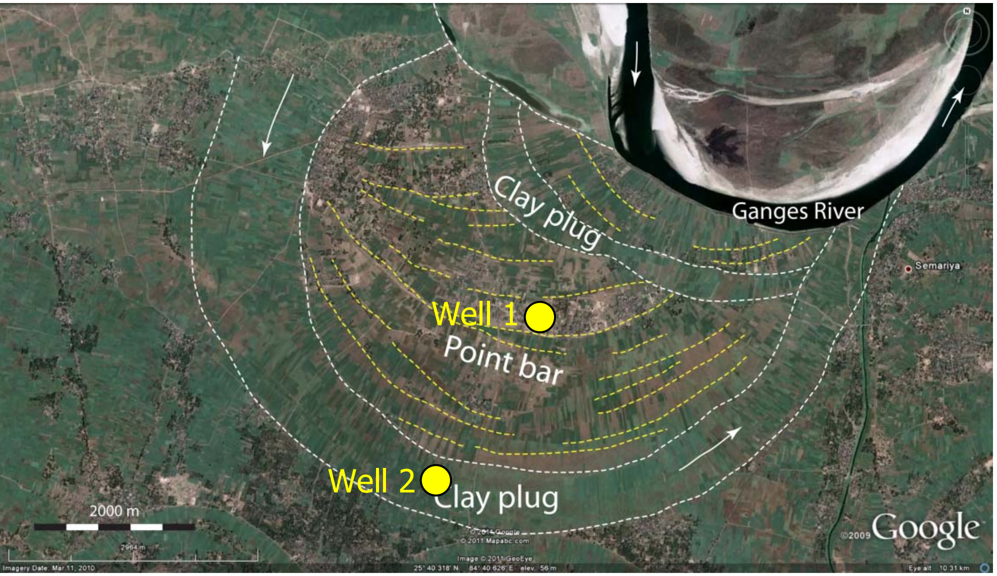
Arsenic entrapment

- Permeable point bar sand enveloped in impermeable mud



http://www.ucalgary.ca/shubbard/research

Results data acquisition 2011



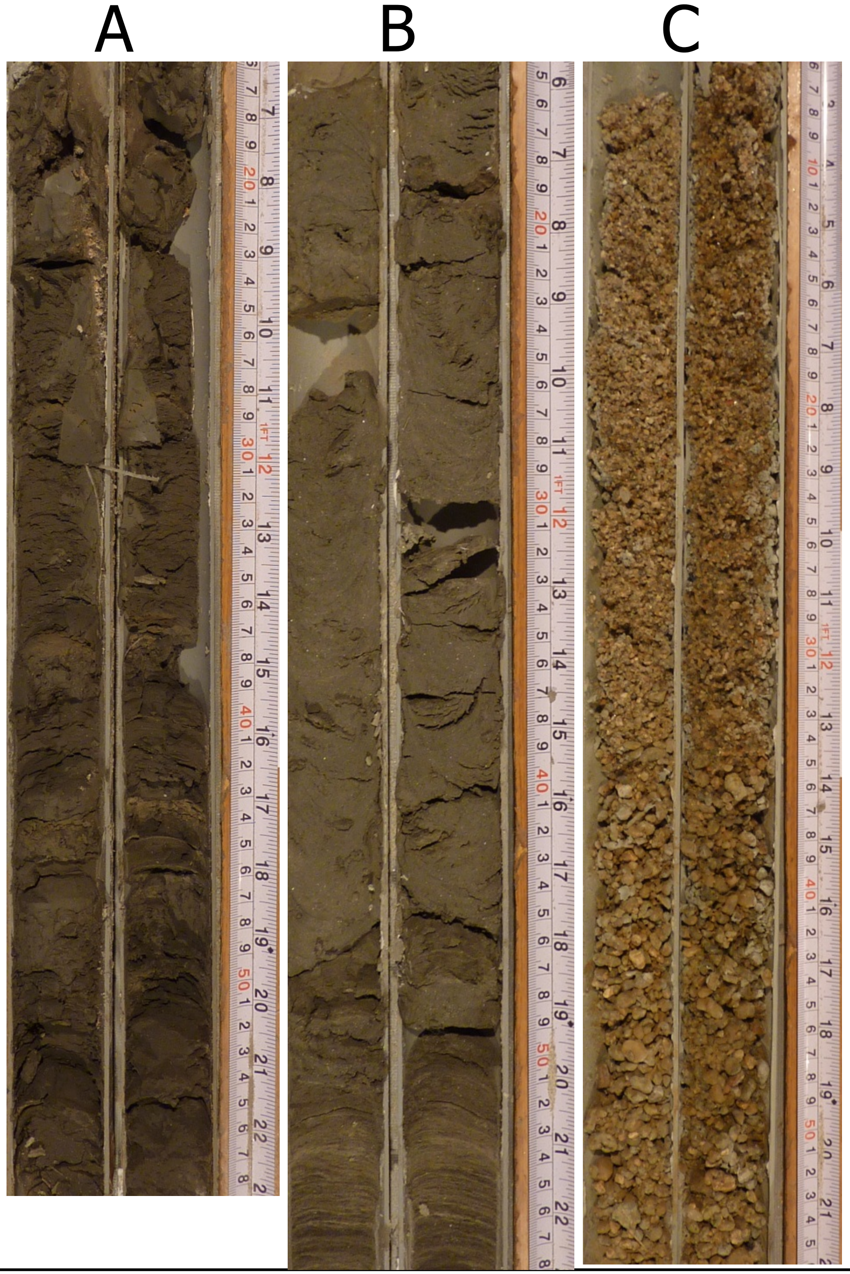
- Two 50-m-deep wells in point bar
- Complete coring
- Gamma-ray and resistivity logging
- Sedimentary petrography analysis
- As-analysis of groundwater

Impression of drilling campaign

Impression of drilling campaign

Lithofacies types

- A: Dark clay, rich in organic carbon
- B: Laminated v.f. sand fining upward to silt
- C: Gravel to v.c. sand



Core analysis

- Well spacing 2.28 km
- Juxtaposition of:
  - Permeable point bar sand (Well 01) and
  - Clay plug rich in organic matter
- Below ~28 m depth:
  - Highly permeable braided river gravelly sand

Impact on flow

- Groundwater trapped in point bars
- Below -28 m: free-moving groundwater flux in high-perm gravel
- Boundary layer: Arsenic-concentration peak

Conclusions

- Arsenic has a geogenic origin
- Arsenic deposited in solid state in Holocene Ganges River sediments
- Arsenic released to groundwater by microbial action
- Clay plugs rich in organic carbon → source of microbial action
- Adjacent point bar sand bodies are stratigraphic trap for arsenic-contaminated water in the Ganges River flood basin


Thanks for your attention!