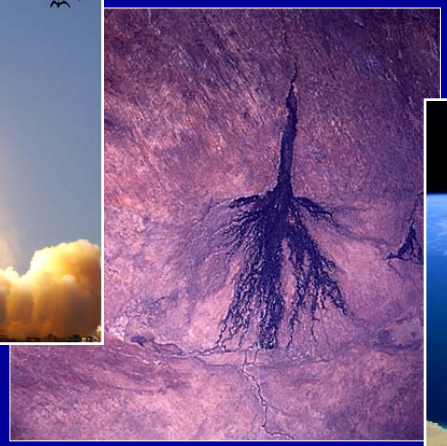
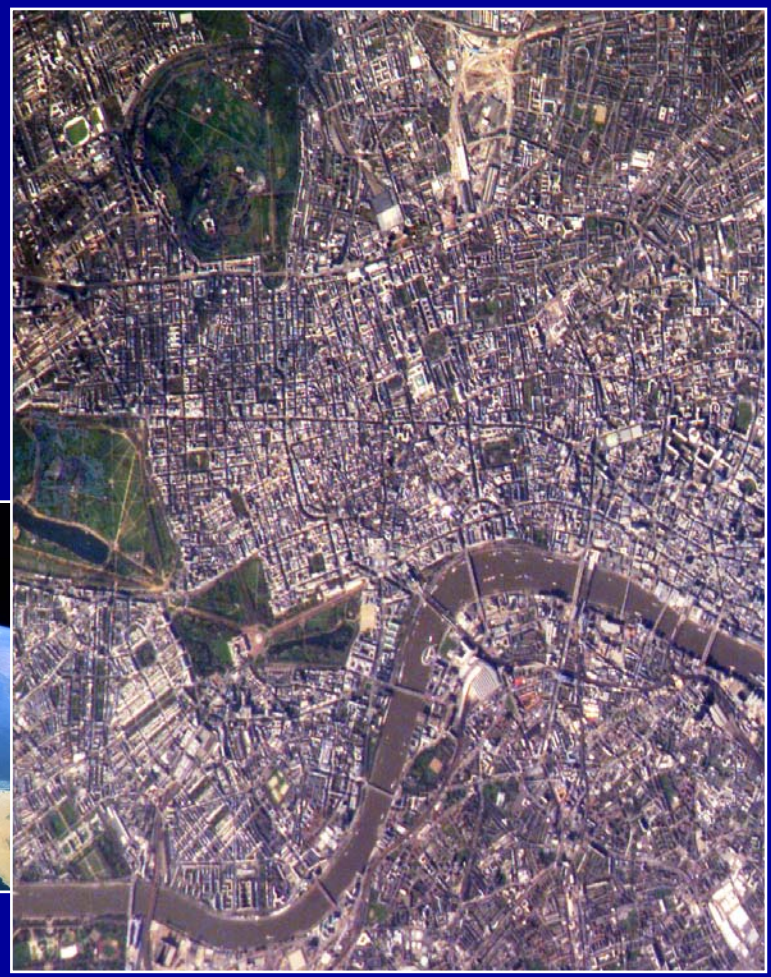
Space Station Views of African Sedimentary Basins — Analogs for Subsurface Patterns





M. JUSTIN WILKINSON
Principal Geoscientist
Jacobs Engineering
NASA–Johnson Space Center
Houston Texas

4th Annual African Petroleum Forum, Mayfair, 2007

- Inland deltas — *The Megafan Project* —
  - examples from astronaut/cosmonaut training
- Prediction
- Significance — Examples of hydrocarbon-charged megafans

- Exploration applications —
  - focus points – apexes
  - stream habit
  - shape
  - nesting patterns — on different continents
  - stratigraphic traps

- Coastal megafans —

Earth Observations Station Message for 25-AUG-2006/GMT Day 237
Message Generated: 24-AUG-2006

Due to the planned launch of STS115 on August 27 (GMT 239), CEO will generate a target message tomorrow (GMT 237) for Saturday August 26 (GMT 238). CEO will resume generation of daily target messages on September 11 (GMT 254) assuming the current STS115 timeline does not change. CEO personnel will assist with image analysis operations during the STS115 mission.

While in XPOP attitude, flight rule constraints will be in effect for use of the Science Window: it is only available for use for ~1/4 of each orbit when it is in trail (not facing into the RAM). This reduces the number of near-vertical targets that can be obtained through the Science Window. Targets are divided into (i) those that can be acquired with the Science Window and (ii) those that cannot. These flight rules do not apply to other windows.

25-AUG-2006/GMT Day 237

GMT	Site	Lat	Lon	Lens
06:25:41	Mud flow, Indonesia	17.1S	107.7E	800

Dynamic Event. Thousands of people on the eastern portion of Java (near Surabaya) have been forced from their homes by an ongoing flow of hot mud and gas. The flow originates from a breach in an underground drilling project. The mud now covers an area of approximately 20 kilometers. Look to the left or right of track (Fig. 1) for a widespread brown to dark brown coating on the ground surface and in stream channels.

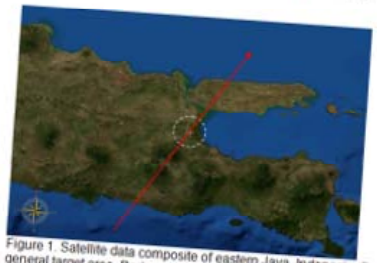


Figure 1. Satellite data composite of eastern Java, Indonesia. Dashed circle indicates general target area. Red arrow indicates your approximate orbit track.

GMT	Site	Lat	Lon	Lens
14:15:50	Oasis Impact Crater, Libya	23.8N	22.5E	400

Look to the right of track for this 18 km diameter impact crater. While the crater walls are not sharply defined, the circular impact structure is readily visible (Fig. 2).

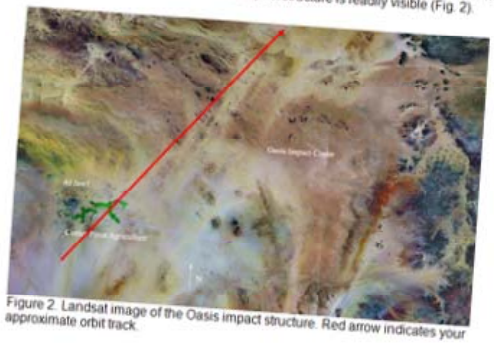


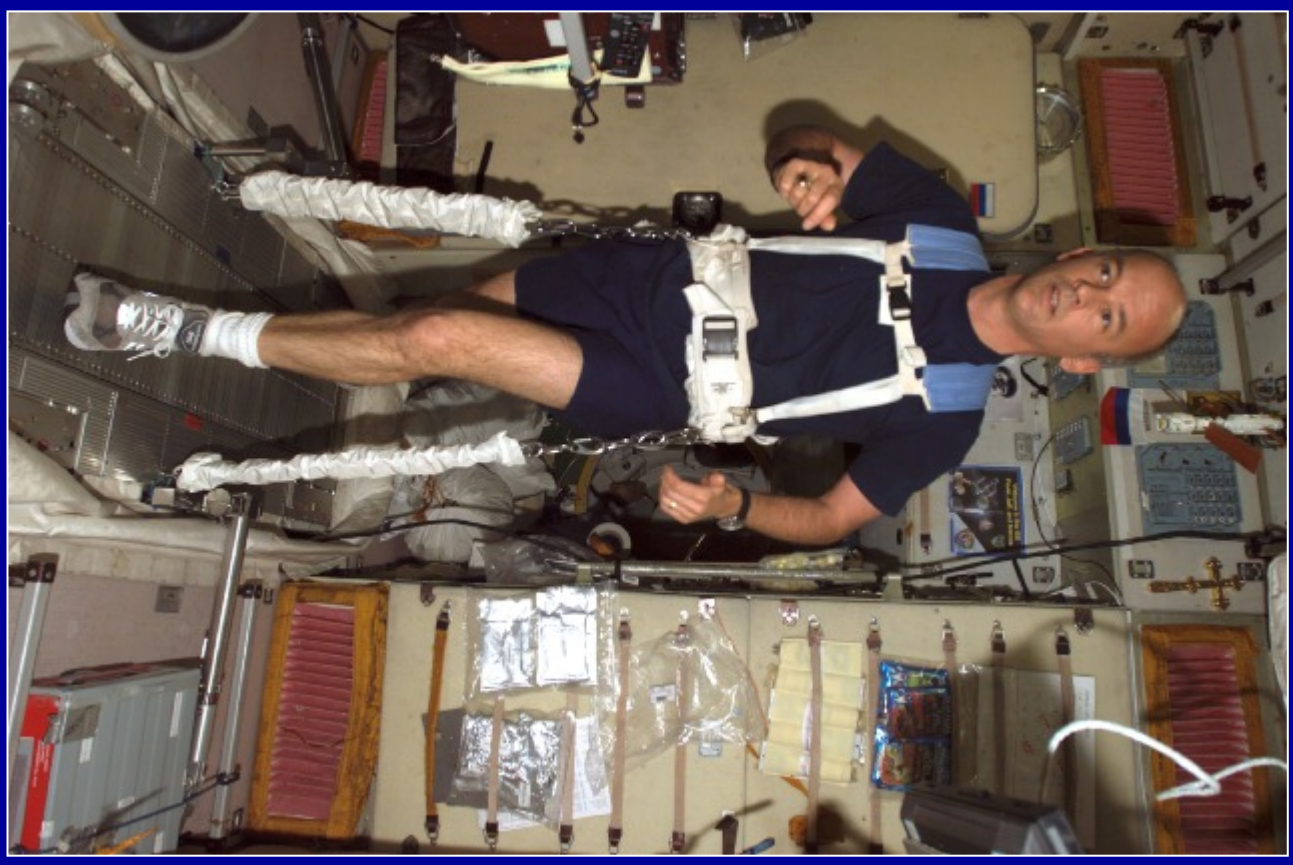
Figure 2. Landsat image of the Oasis impact structure. Red arrow indicates your approximate orbit track.

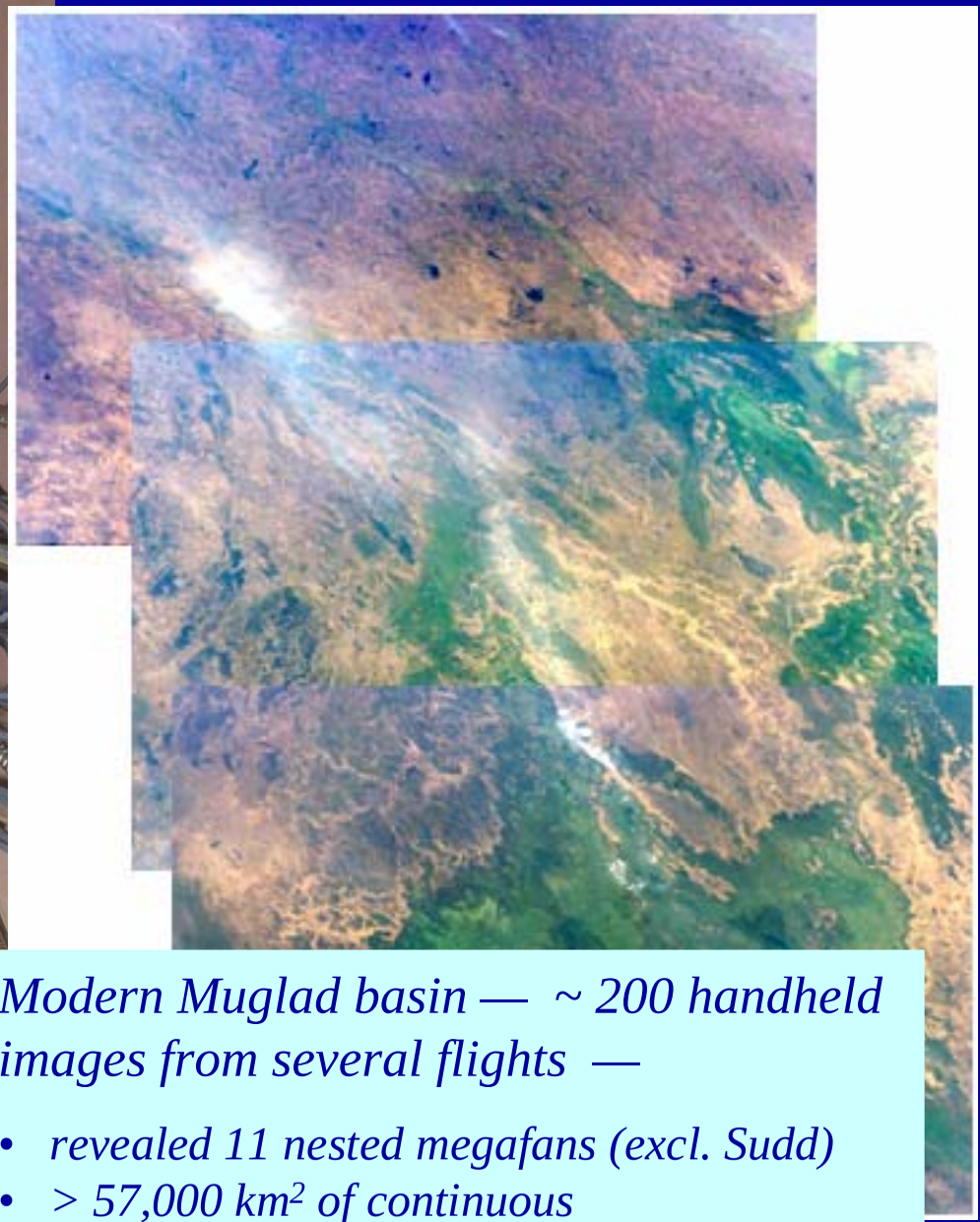
GMT	Site	Lat	Lon	Lens
17:02:27	Pilcomayo R dynamics, N Argentina	25.1S	61.8W	400

Look to either the left or right of track to map the channel course of this river. The sunglint point will be towards the left of track, and may be helpful in highlighting the river channel as it flows out from the Andes.

GMT	Site	Lat	Lon	Lens
18:47:00	Tropical Storm Debby, Atlantic Ocean	15.3N	54.3W	180

Dynamic Event. This tropical storm is predicted to attain hurricane strength over the next two days. Look to the right of track for cloud structure and developing outflow bands.

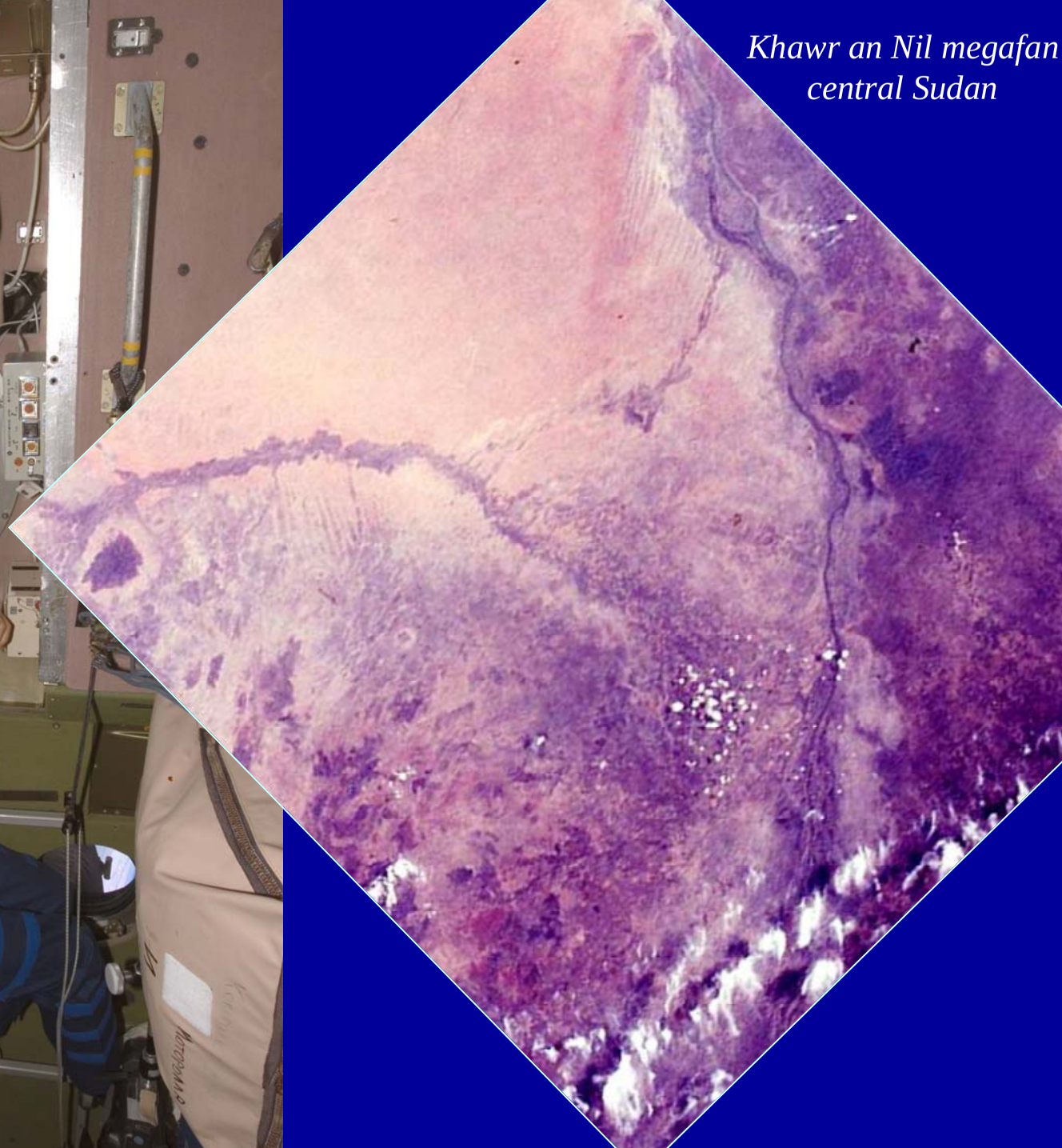




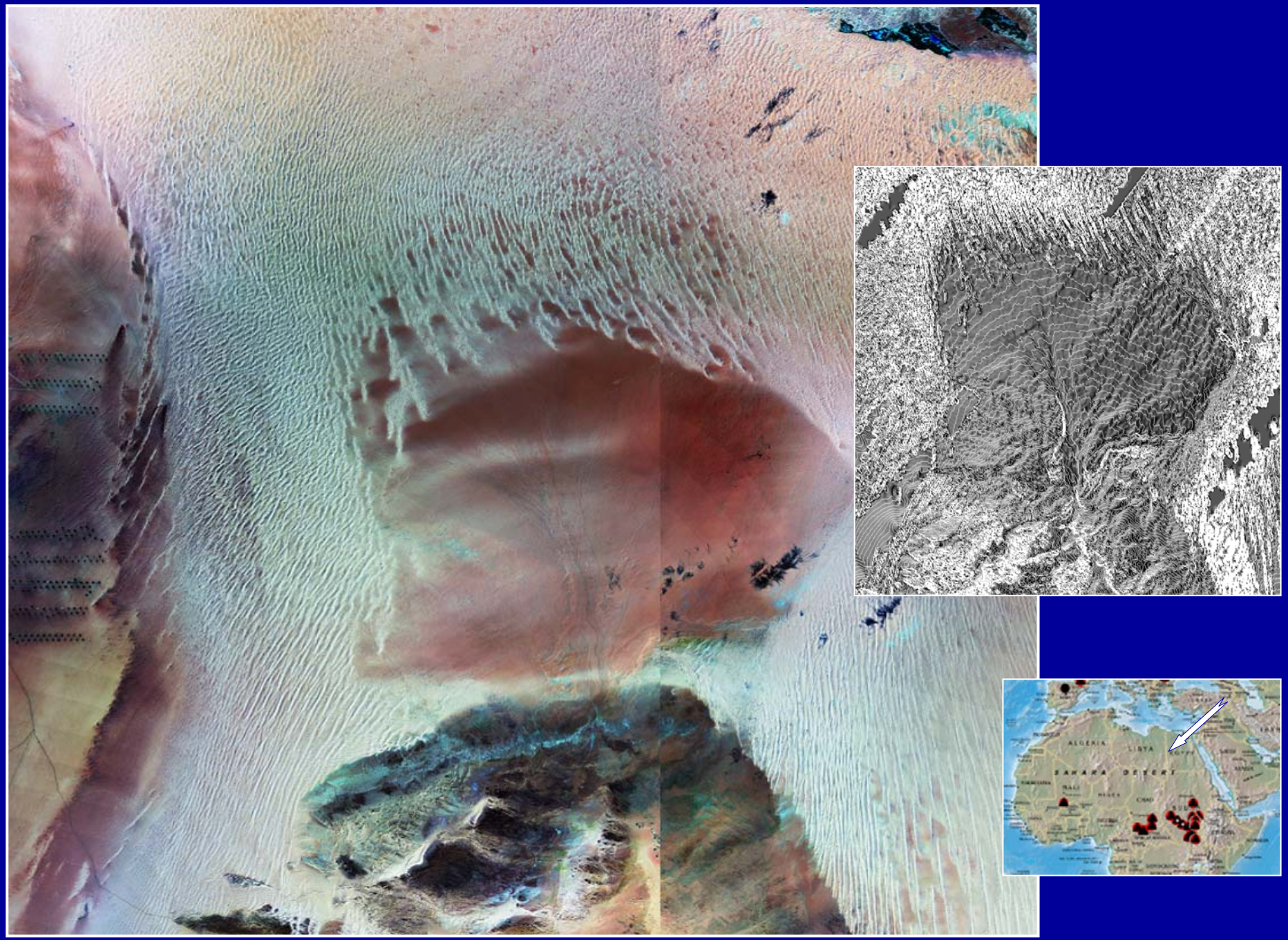
Modern Muglad basin — ~ 200 handheld images from several flights —

- *revealed 11 nested megafans (excl. Sudd)*
- *> 57,000 km^2 of continuous megafan surface mapped (LANDSAT map)*

Garonne-Arros compound megafan, southern France – Pyrenees STS51B-31-82



Khawr an Nil megafan
central Sudan

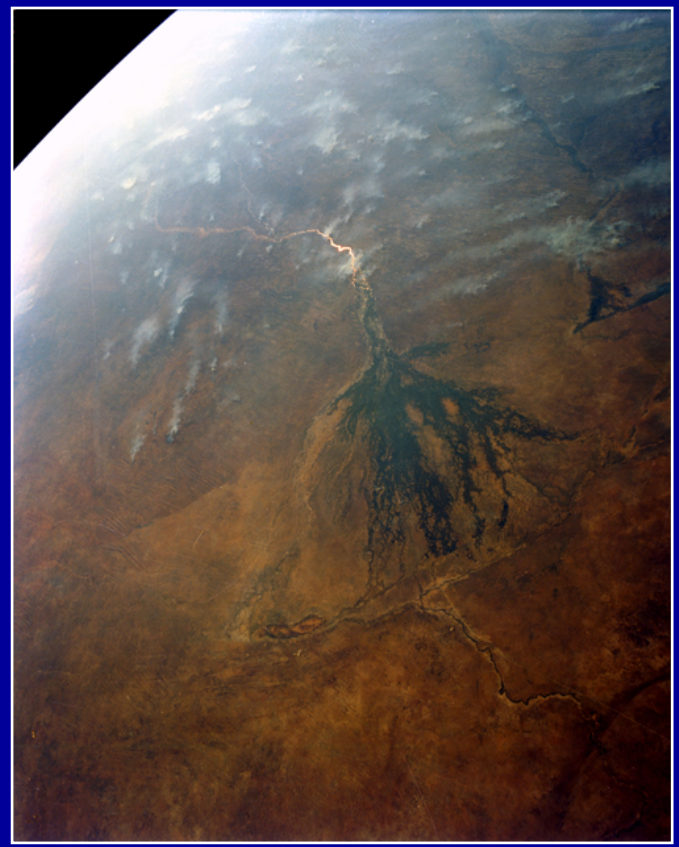


Calanscio megafan, Western Desert, Egypt, Landsat ETM+ image -- with SRTM contours

Non-functional megafans —

Cunene megafan
Etosha Pan

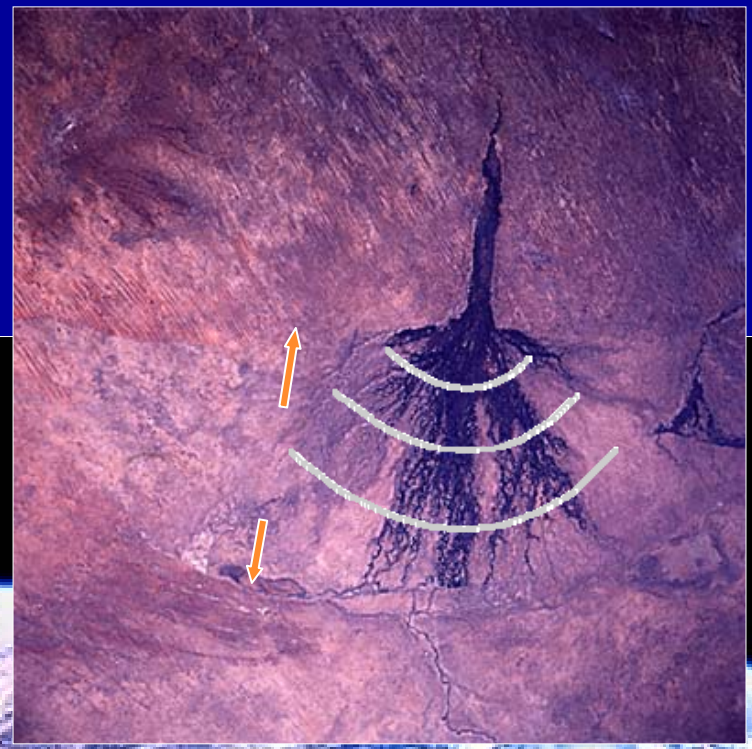
Okavango River megafan



Global study of Megafans —

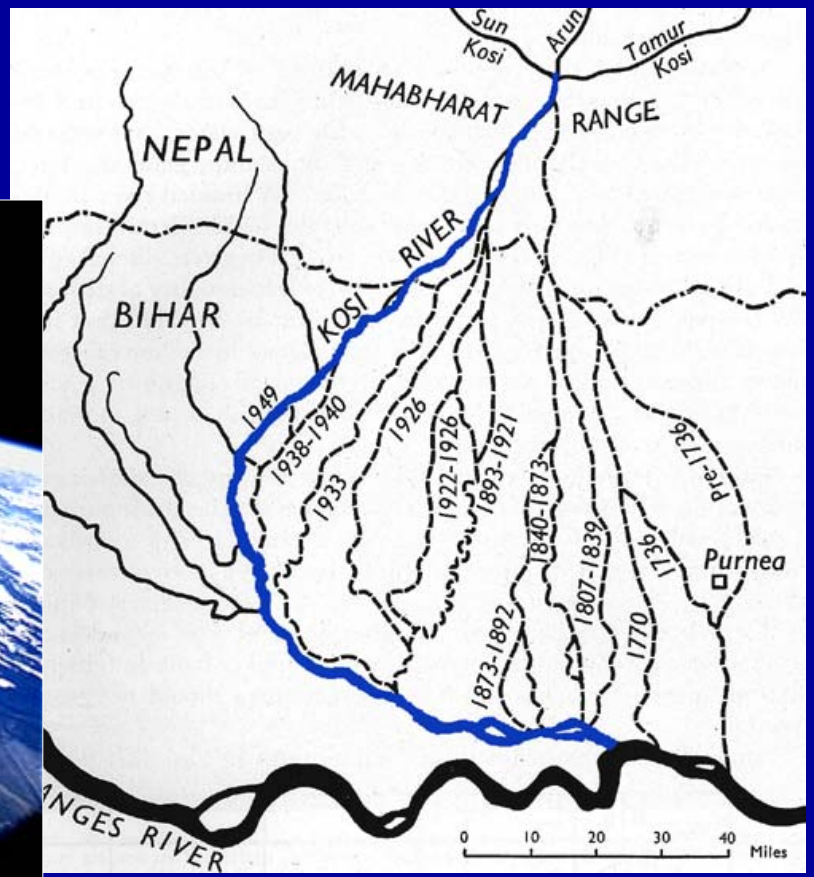
- river-made
- very smooth surfaces, of low slope
- fan-shaped, *cone of sediment* (convex contour elevation lines)
- mean radius 100 – 300 km
- areas from 7000 – 200,000 km^2
- *different from alluvial fans, floodplains, deltas*

Okavango R. inland delta, Botswana



Kosi R. fan, India

- "switching" behavior — Kosi River —
  - cross entire surface of fan
  - average rate ~19 yr between switching events

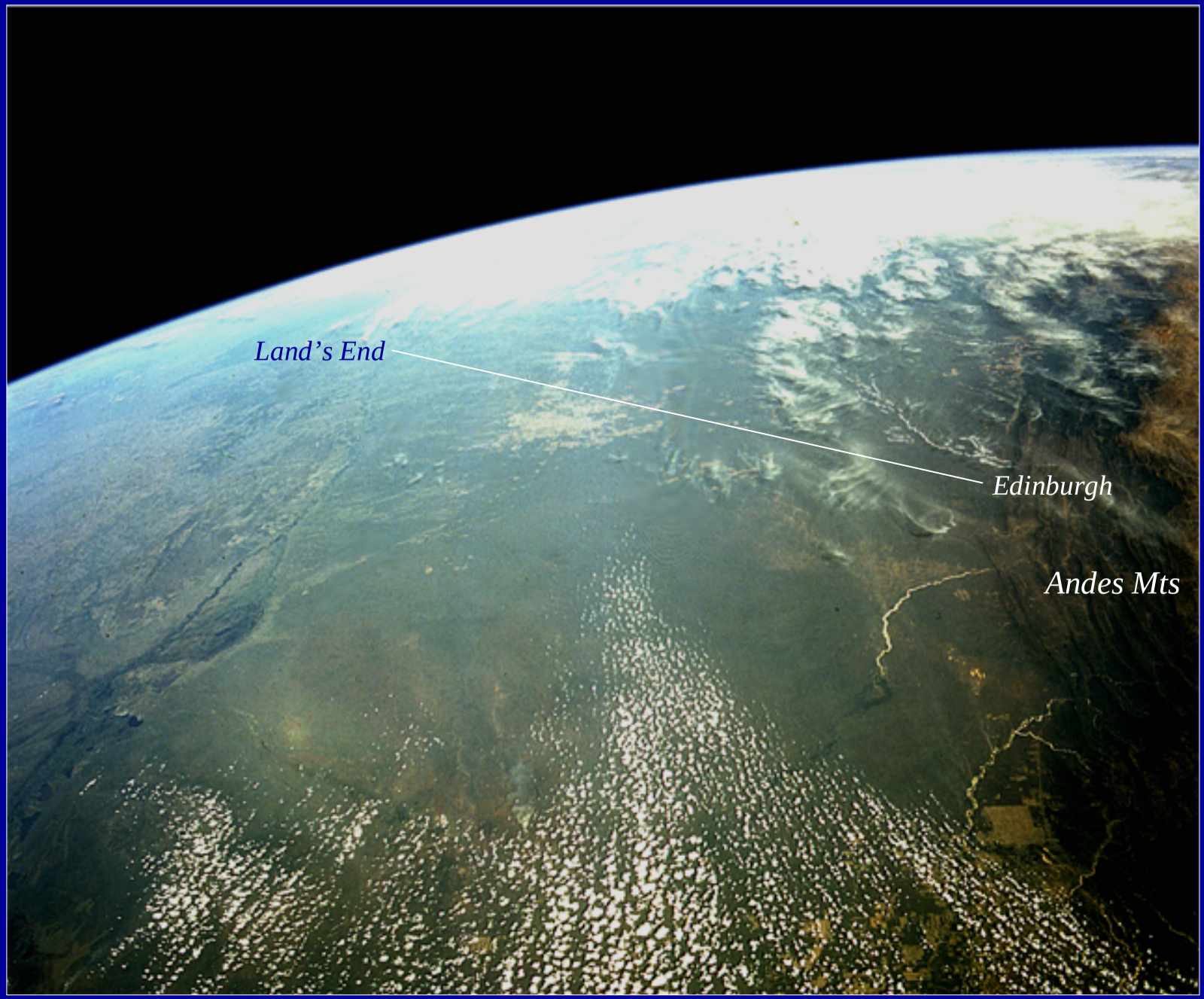


Kosi R. avulsions

Distribution—

- >100 probable large fans identified worldwide, thus far —
- basin type —
  - foreland basins—56%
  - peri- and intracratonic basins—36%
  - rift basins—6%
  - interorogenic basins—2%
- occur in all climates

mapped from Space Shuttle photographs, other space-based imagery, maps (especially 1:1m ONC charts), various reports



Megafans of Northern Argentina; Parana megafan, inset

Unexpected conclusions —

Large fans are probably —

- *A New class* of landform feature on the planet (not the freak end point in the alluvial fan continuum)
- *The Norm* in all filling continental basins

- *Prediction* — successful prediction of location is now possible

Significance — hydrocarbons associated with megafans

Paleogeography —

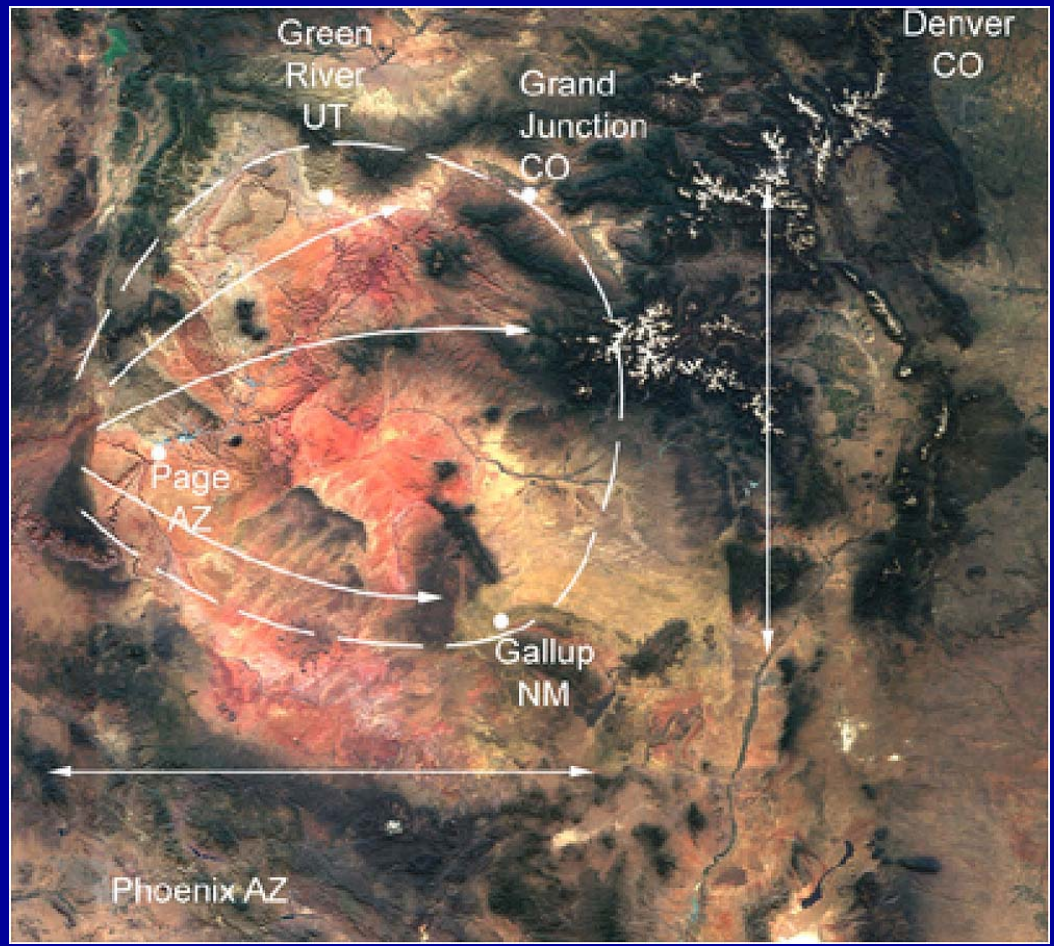
Continental fluvial fan, Upper Jurassic rocks, Colorado, Utah —

Large subsurface fan structure —

- reconstructed from numerous wells
- hundreds of km in radius

Oil and gas production in —

- Utah
- Colorado



after Jones et al. 2002

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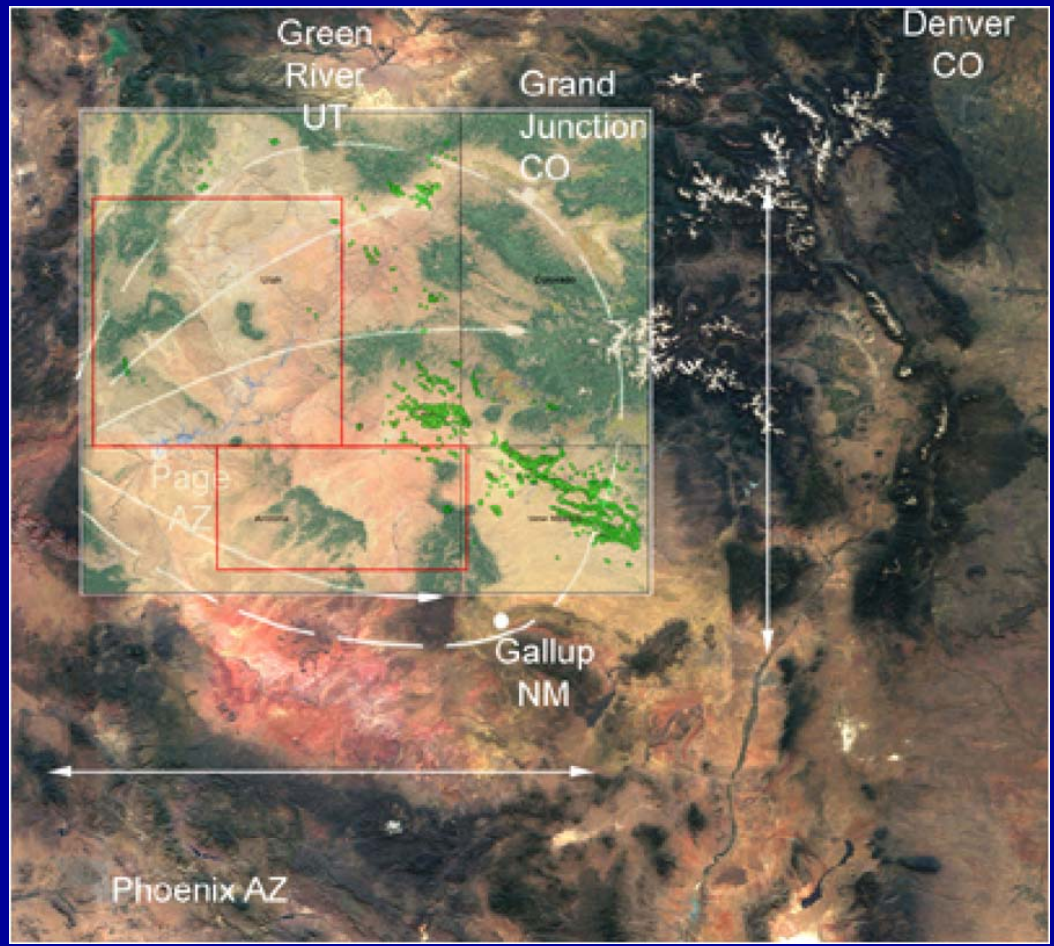
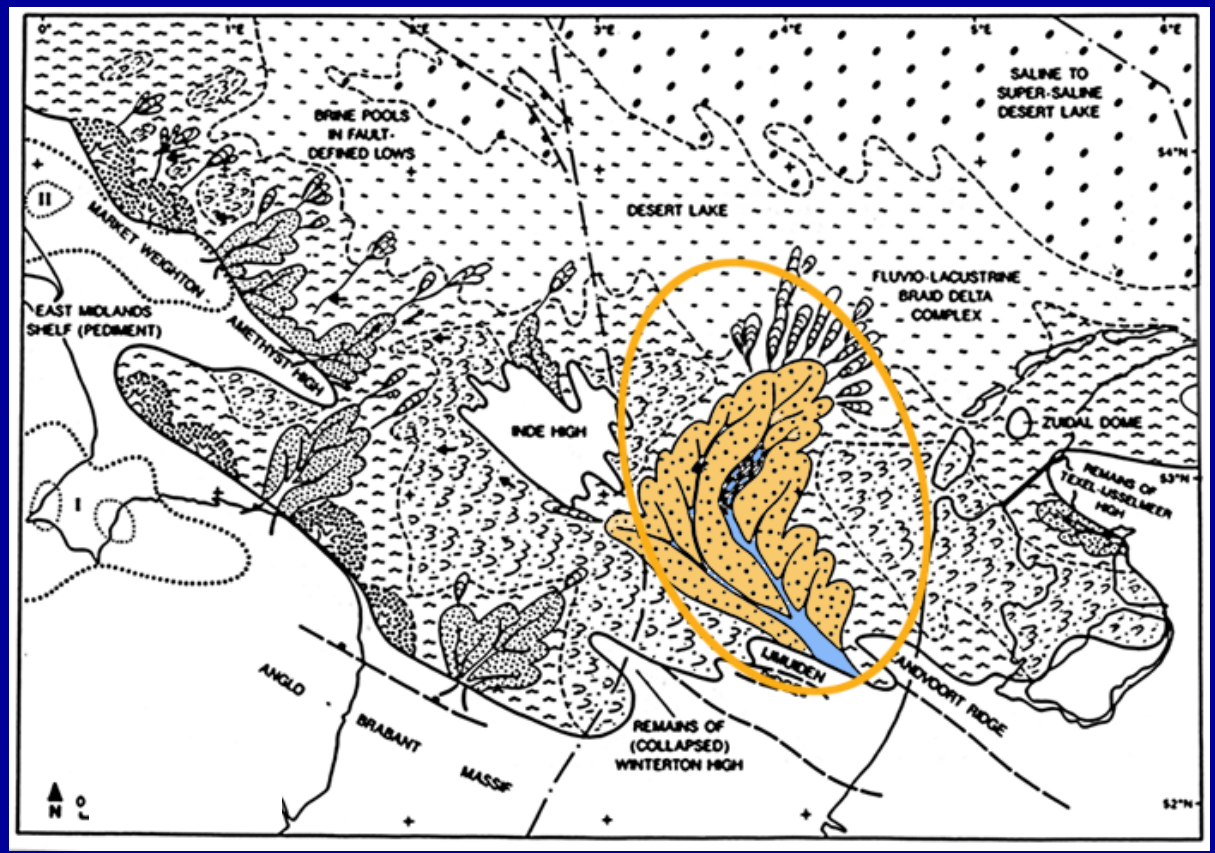


after Jones et al. 2002

Significance — hydrocarbons associated with megafans

Paleogeography of a fluvial desert landscape —



George & Berry 1997

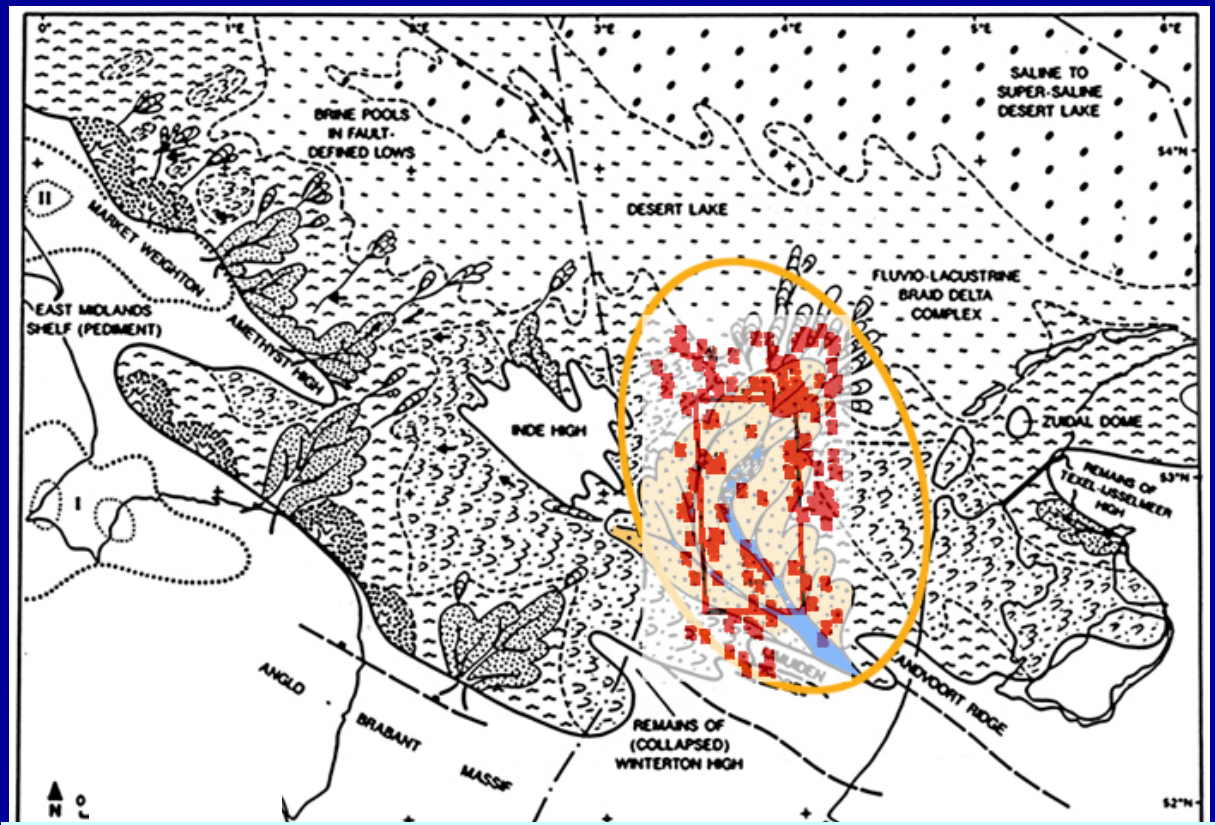
Southern North Sea (Permian) —

– *one large fluvial feature*
– divergent drainage pattern
– on a scale of hundreds of km
– very likely a megafan

– 160 TCF of natural gas

Significance — hydrocarbons associated with megafans

Paleogeography of a fluvial desert landscape —



Southern North Sea (Permian) —

– *one large fluvial feature*
– divergent drainage pattern
– on a scale of hundreds of km
– very likely a megafan

… given the nature of terrigenous sedimentary systems at the basin margin, the potential for stratigraphic traps … is substantially higher than for sequences such as aeolian sands … – *Moscariello, 2005*

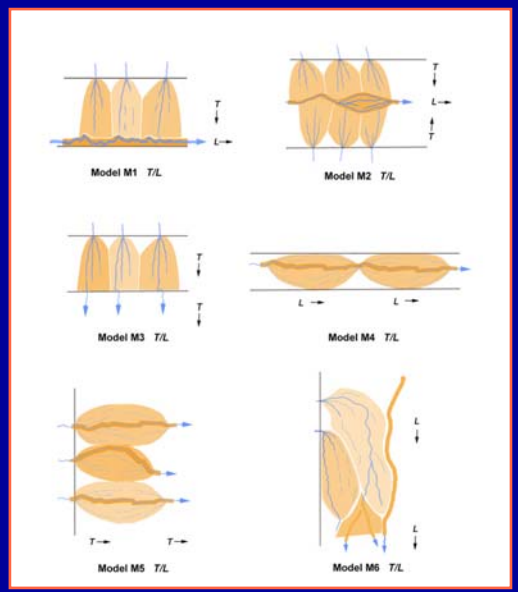
atural gas

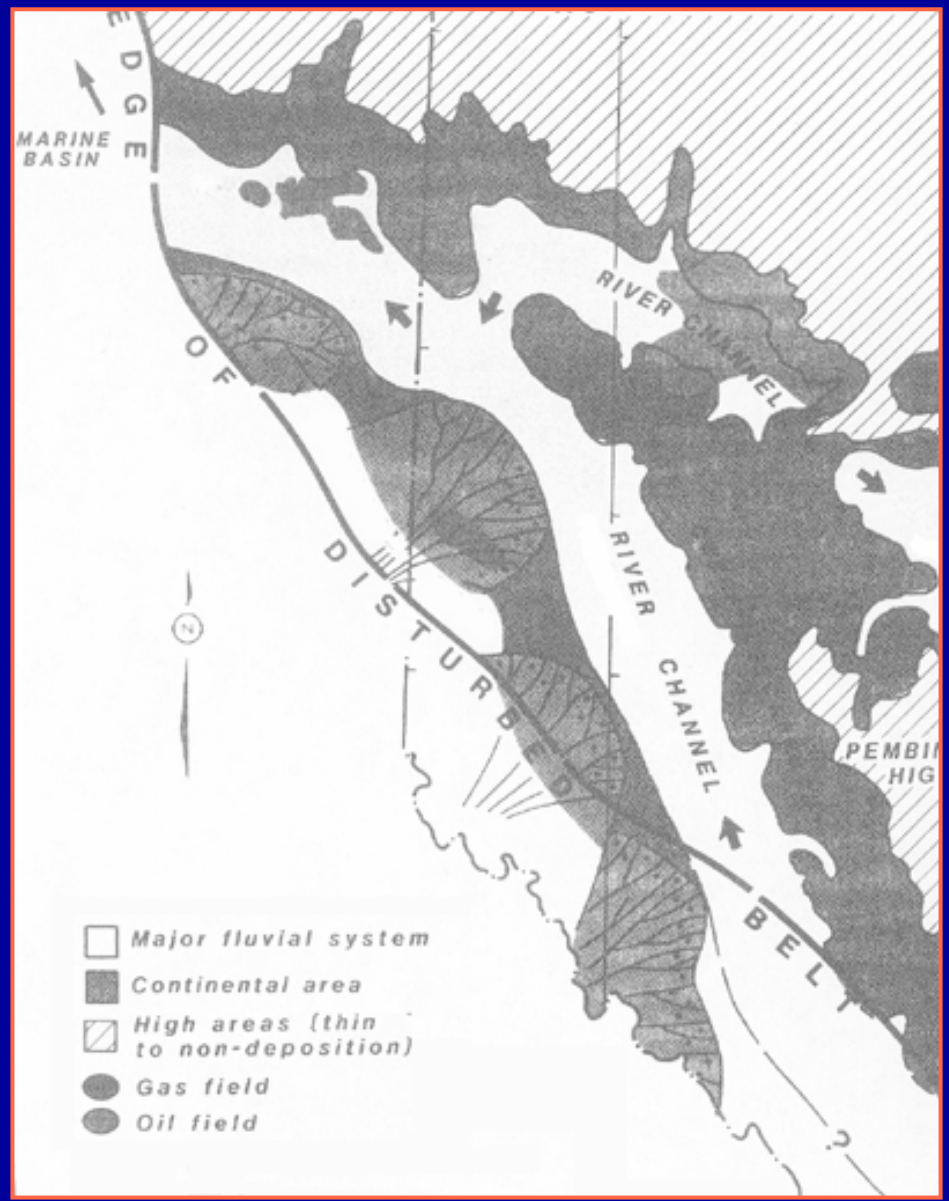
Significance — hydrocarbons associated with megafans

Paleogeography —

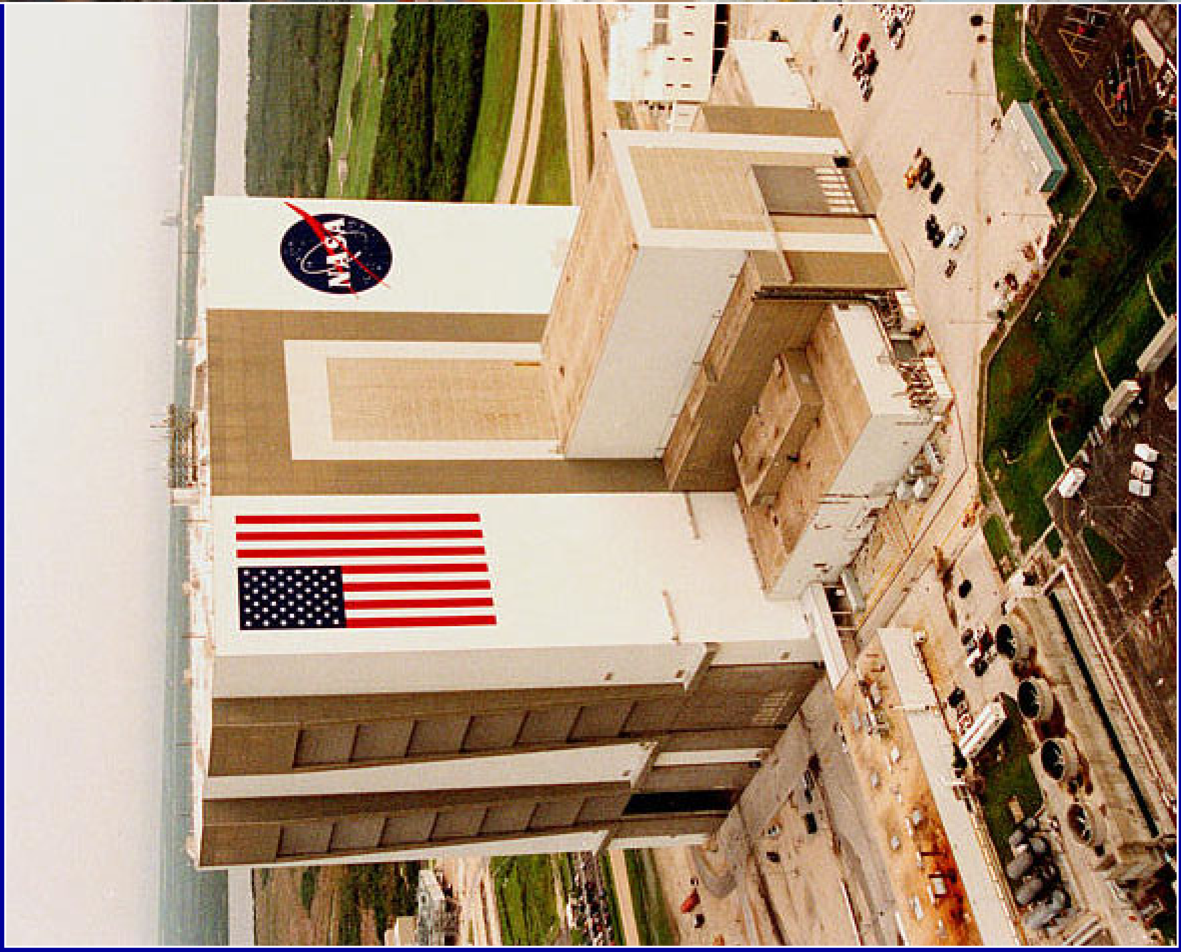
Fluvial continental sediments — mesoscale patterns in Rocky Mts foreland (Upper Cretaceous–Early Tertiary rocks)

- dominated by *several large fans*
- "gas saturated over a wide area"



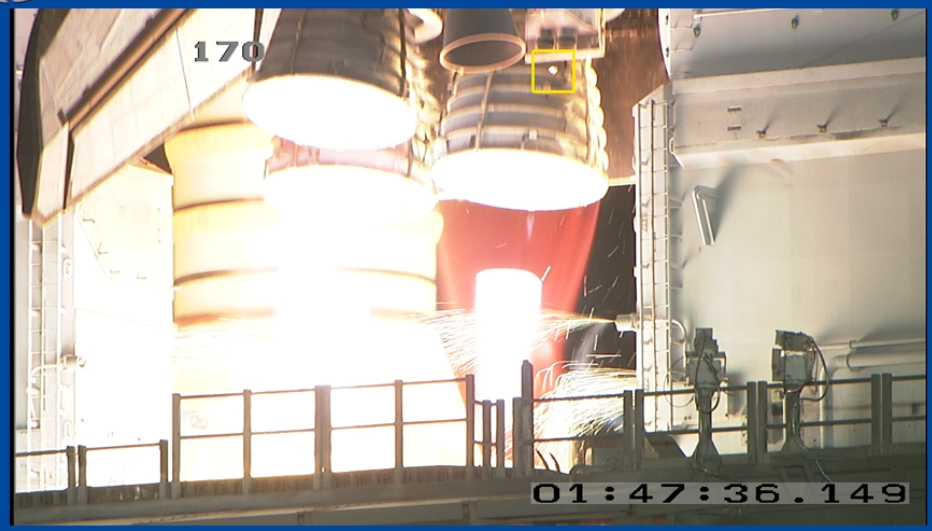


Masters, 1984




NASA

Camera OTH170 STS-116



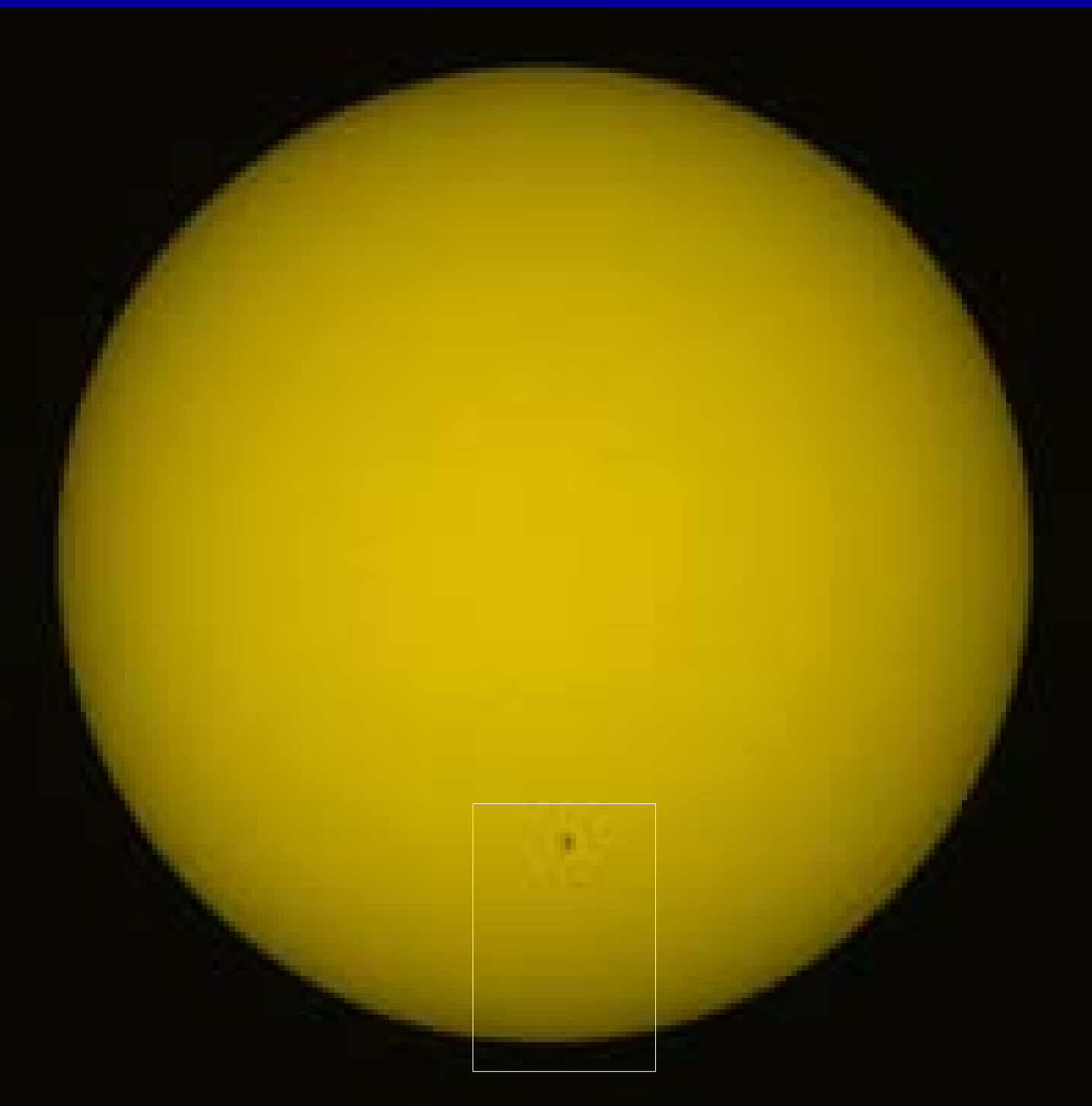
Debris Falls Aft (probably RCS paper) of the Right RCS Stinger

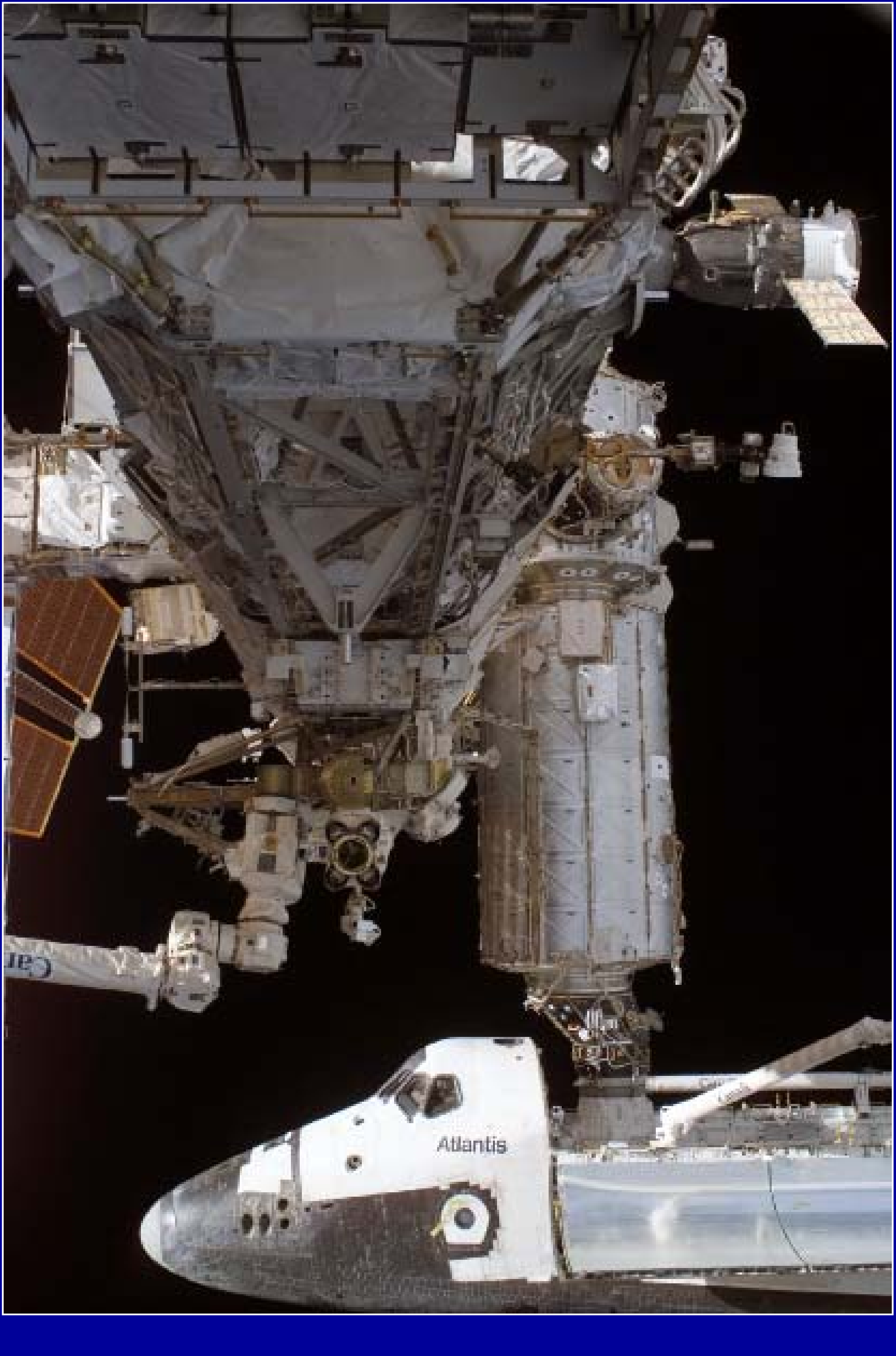
JSC Image Science & Analysis Group

Camera OTH160 STS-116

bris Noted In Exhaust Plume After Liftoff

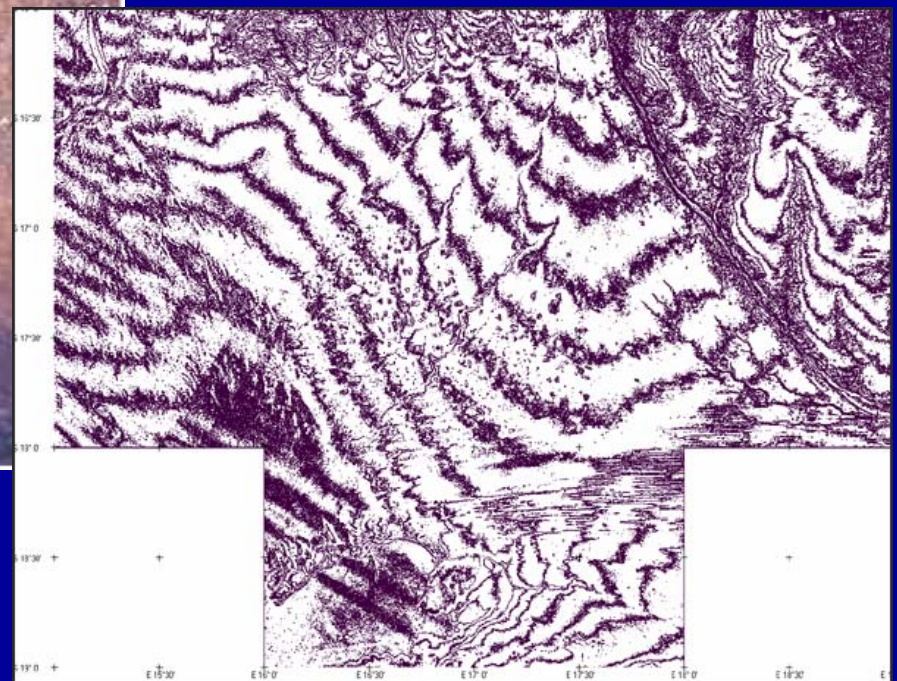
JSC Image Science & Analysis Group




Atlantis

Prediction —

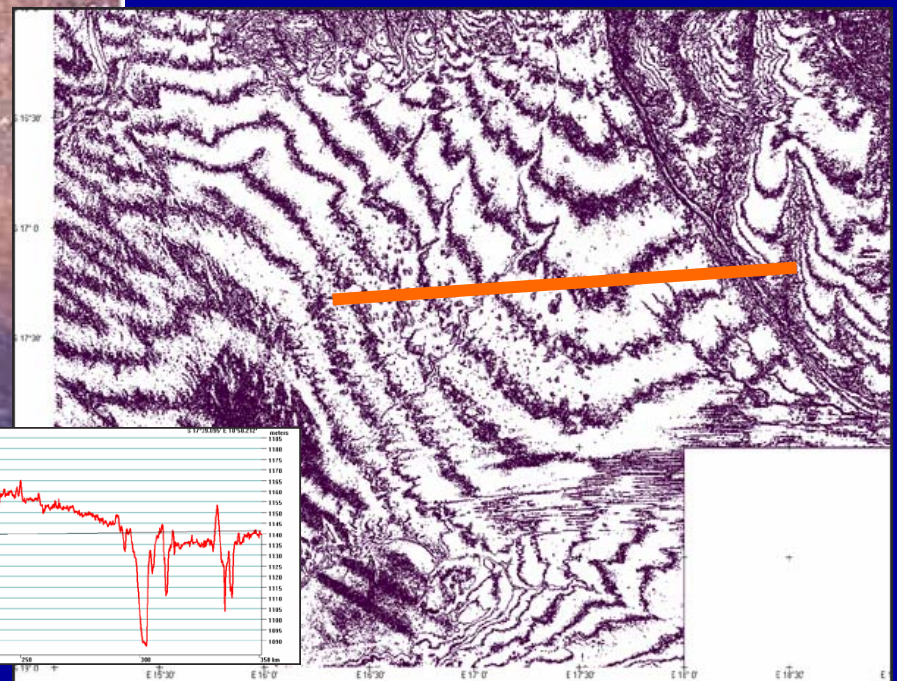
new megafan?

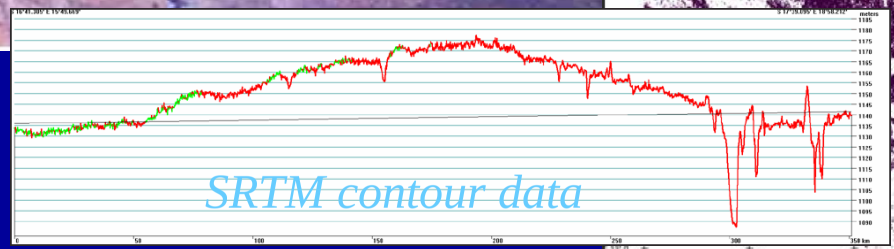


SRTM contour data

Prediction —

new megafan?

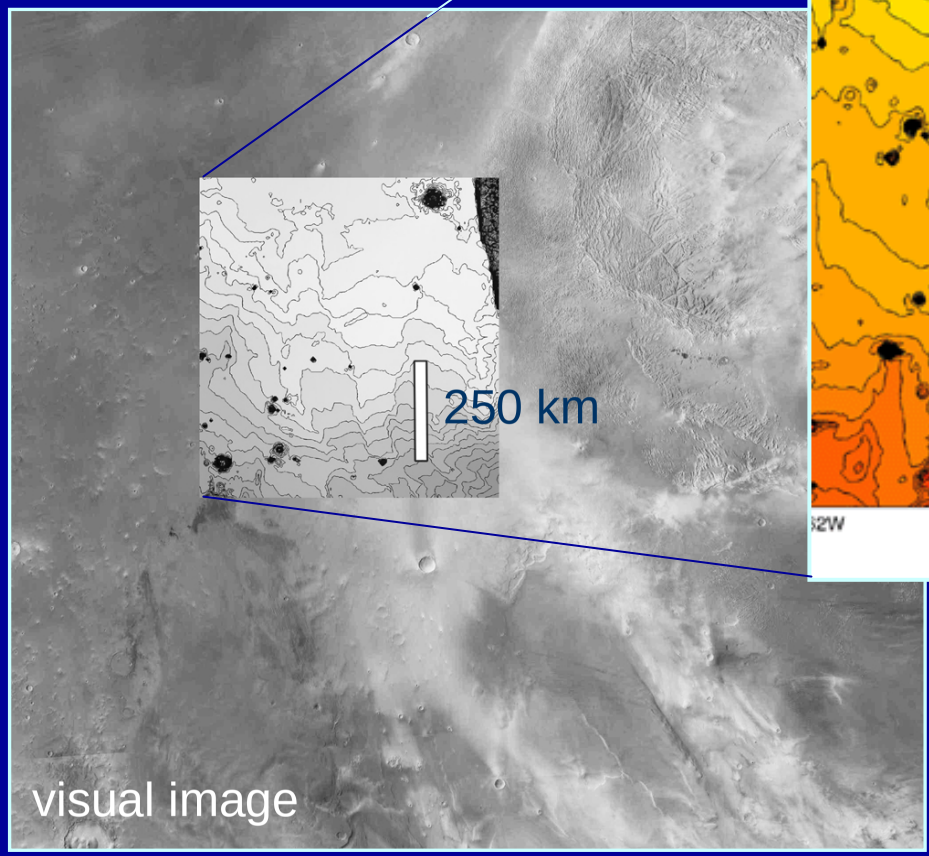


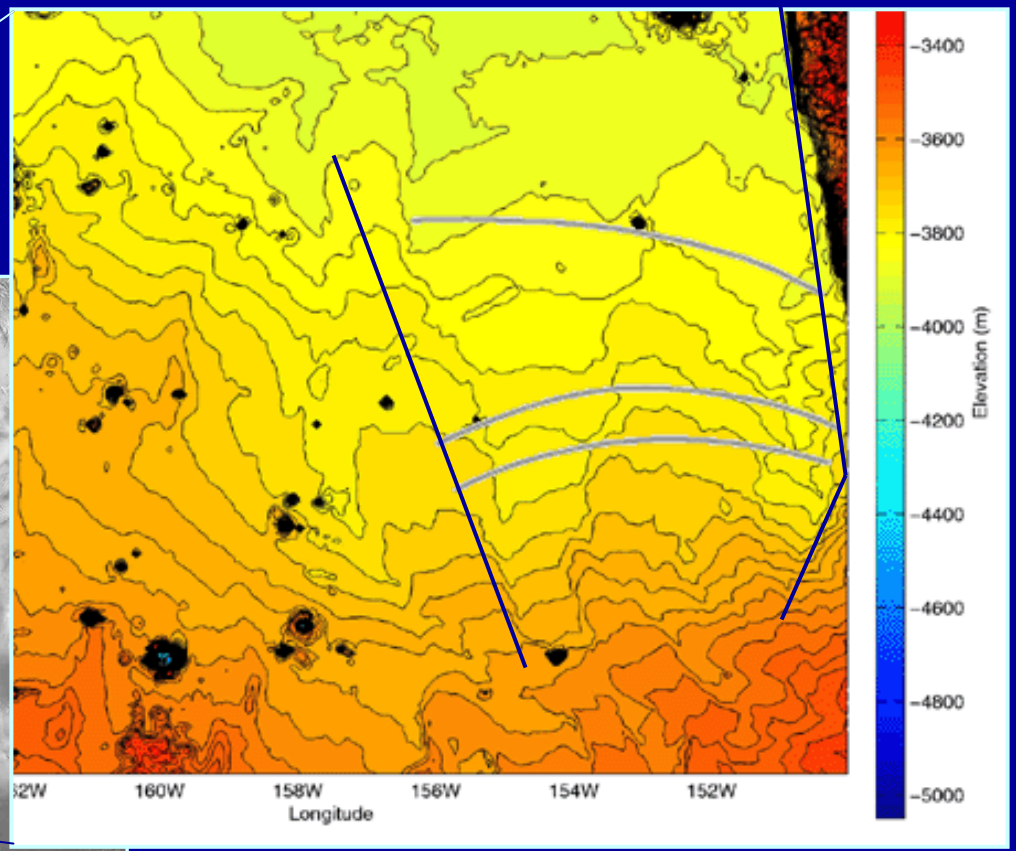


SRTM contour data

Prediction —

Reconstructed elevation contours —
- indicate a cone, subsequently twice incised
- indicate slopes precisely within the range of Earth megafans





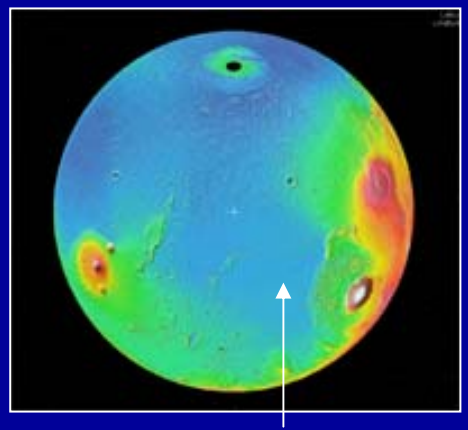
Elevation contours from MOLA data (Mars Orbiter Laser Altimeter)

Prediction —

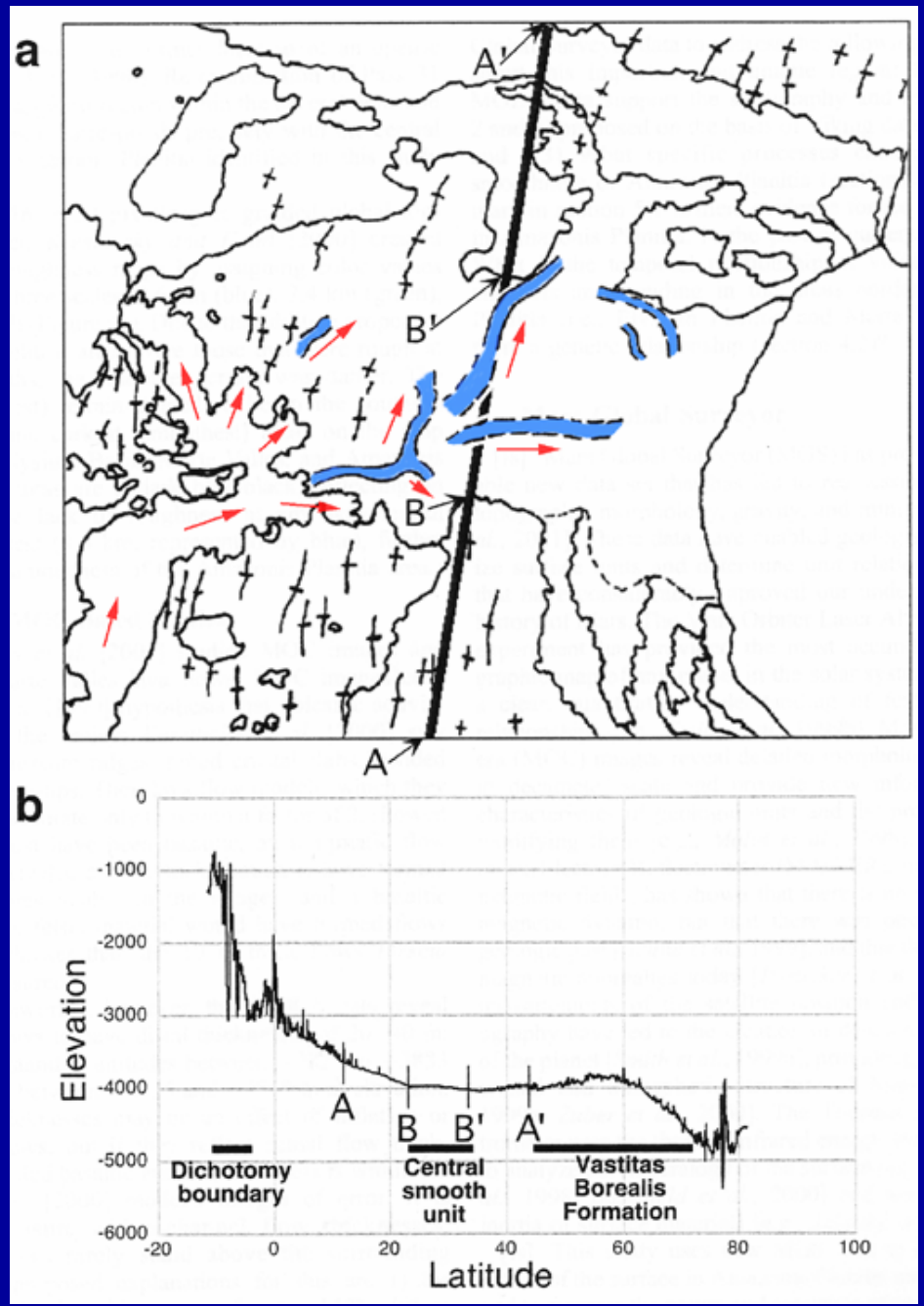
Amazonis Planitia

Flattest plans on Mars (Amazonis Planitia) —

- "outwash plains" made by rivers
- downstream of Marte Valles
- apparent fan radius 880 km



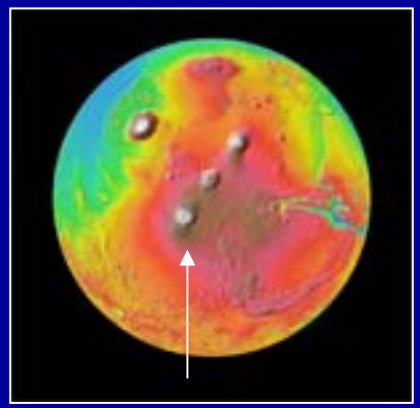
Amazonis Planitia, flattest terrain on Mars, Achp unit, "outwash" plains
From MOLA data, apparent radius of zone of dispersive flow 885 km
(after Fuller and Head 2002)

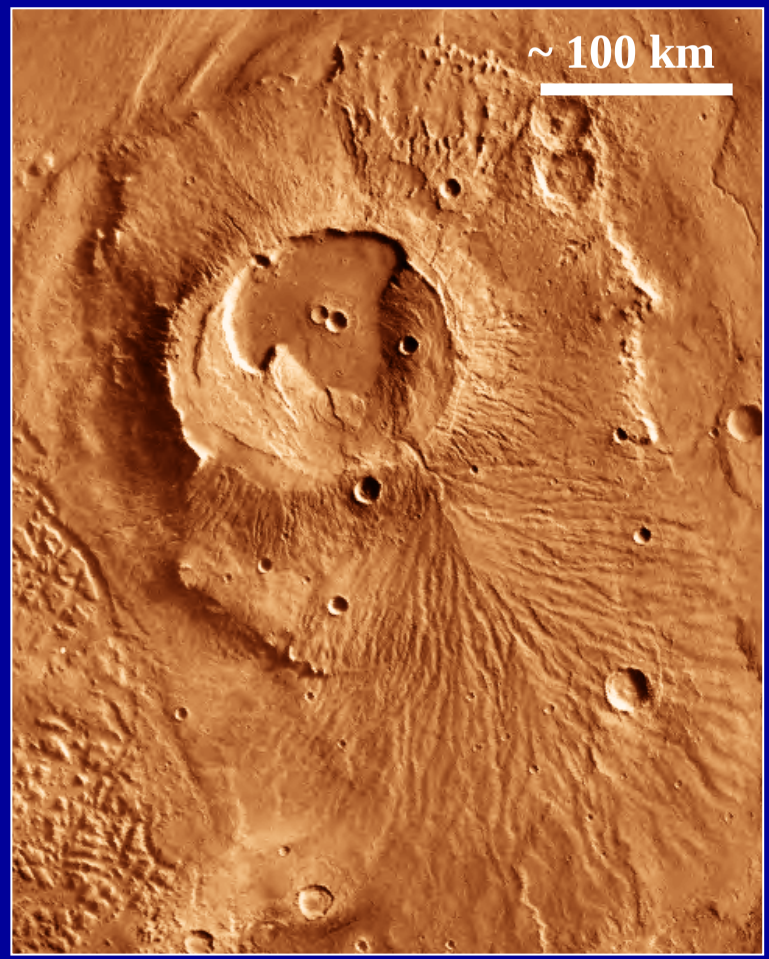


Prediction —

Large fan on southern flank of Apollinaris Volcano —

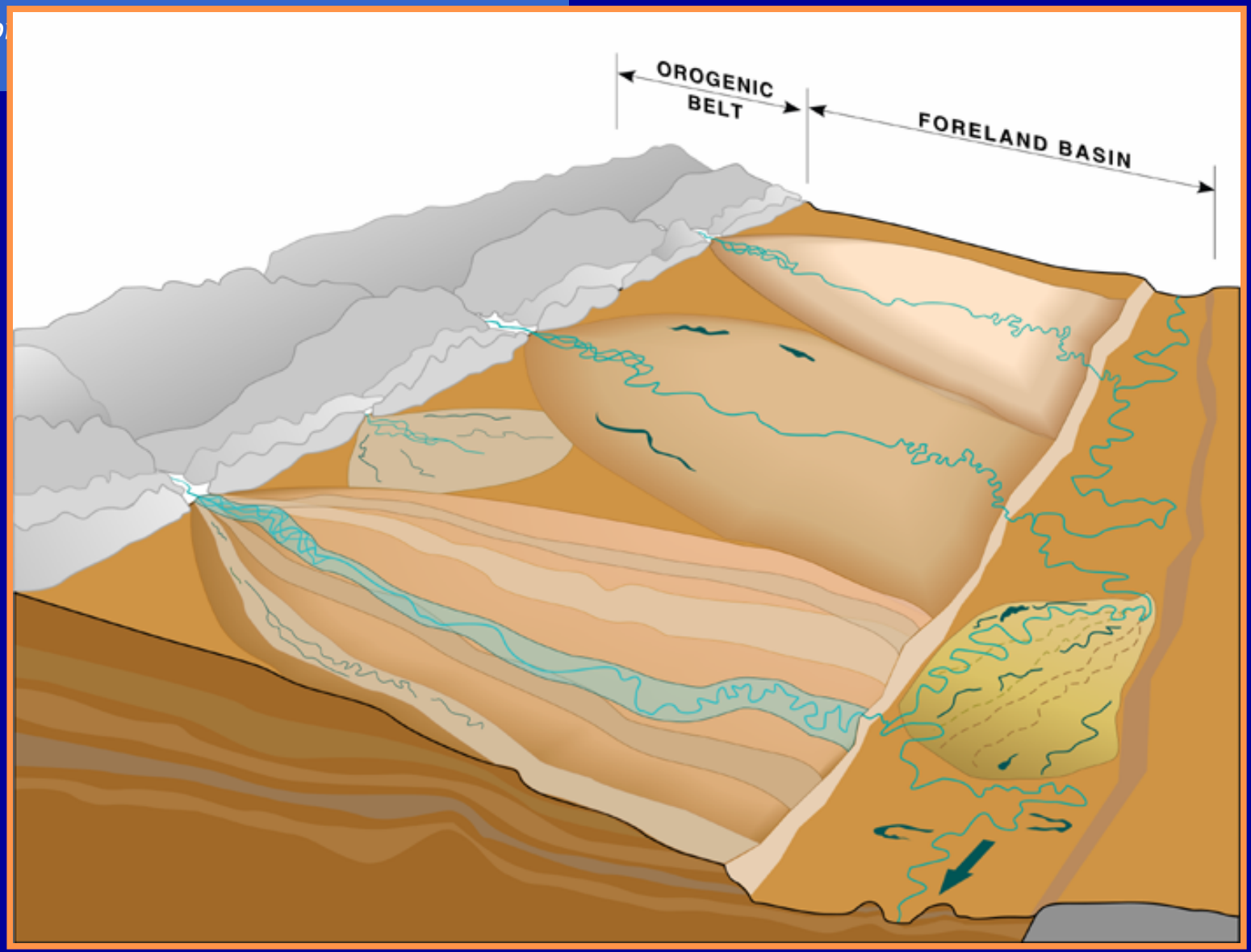
— may be a lava fan
— or an outflow (fluvial) fan





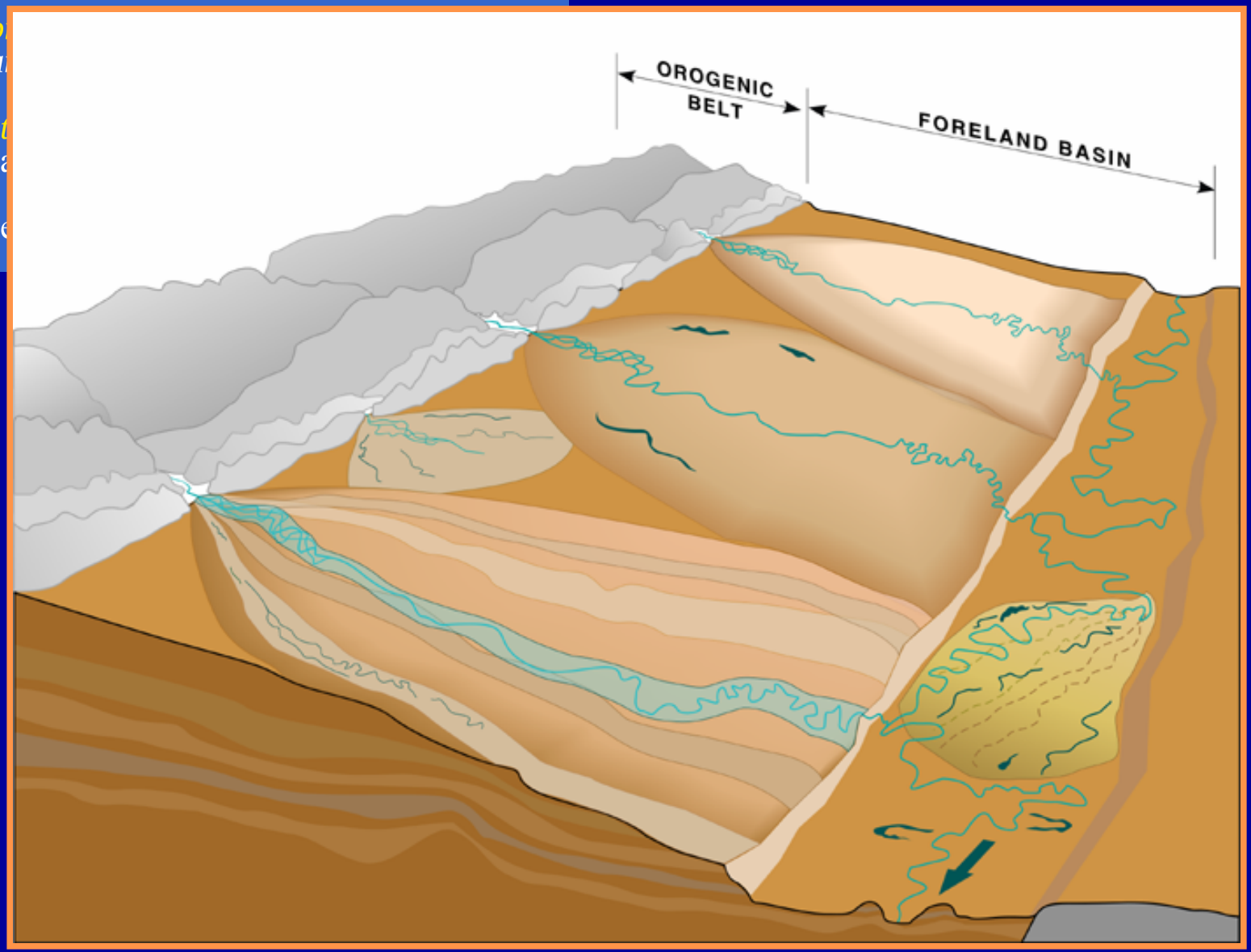
Exploration — Channel types —

- *b*



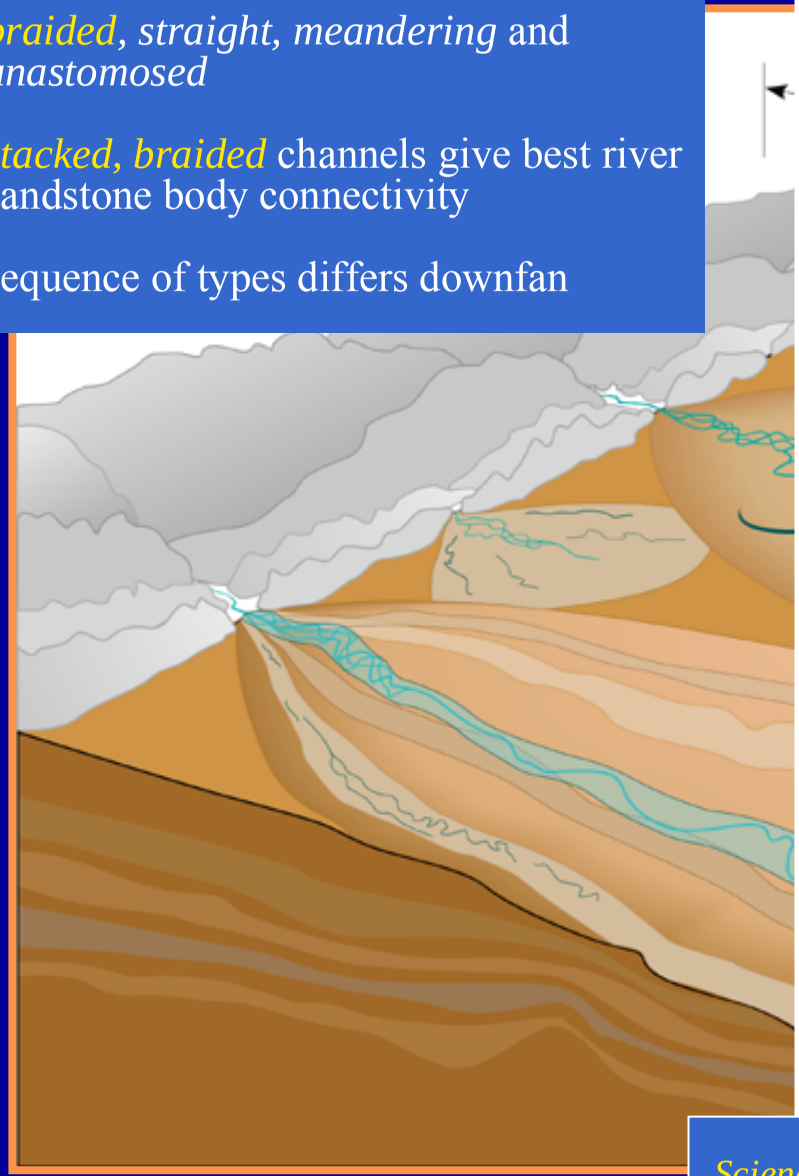
Exploration — Channel types —

- *b*
  a
- *st*
  sa
- se



Exploration — Channel types —

- *braided*, *straight*, *meandering* and *anastomosed*
- *stacked*, *braided* channels give best river sandstone body connectivity
- sequence of types differs downfan



ISS imagery and a possible new river pattern

River patterns accepted in geology are : *meandering, straight, braided, anastomosing* (insets)

Detailed ISS image mosaic of the Bermejo River (Bermejo megafan, N Argentina), strongly suggests that a fourth pattern needs to be defined :

angular pattern

> straight reaches alternating with tight (low radius) bends

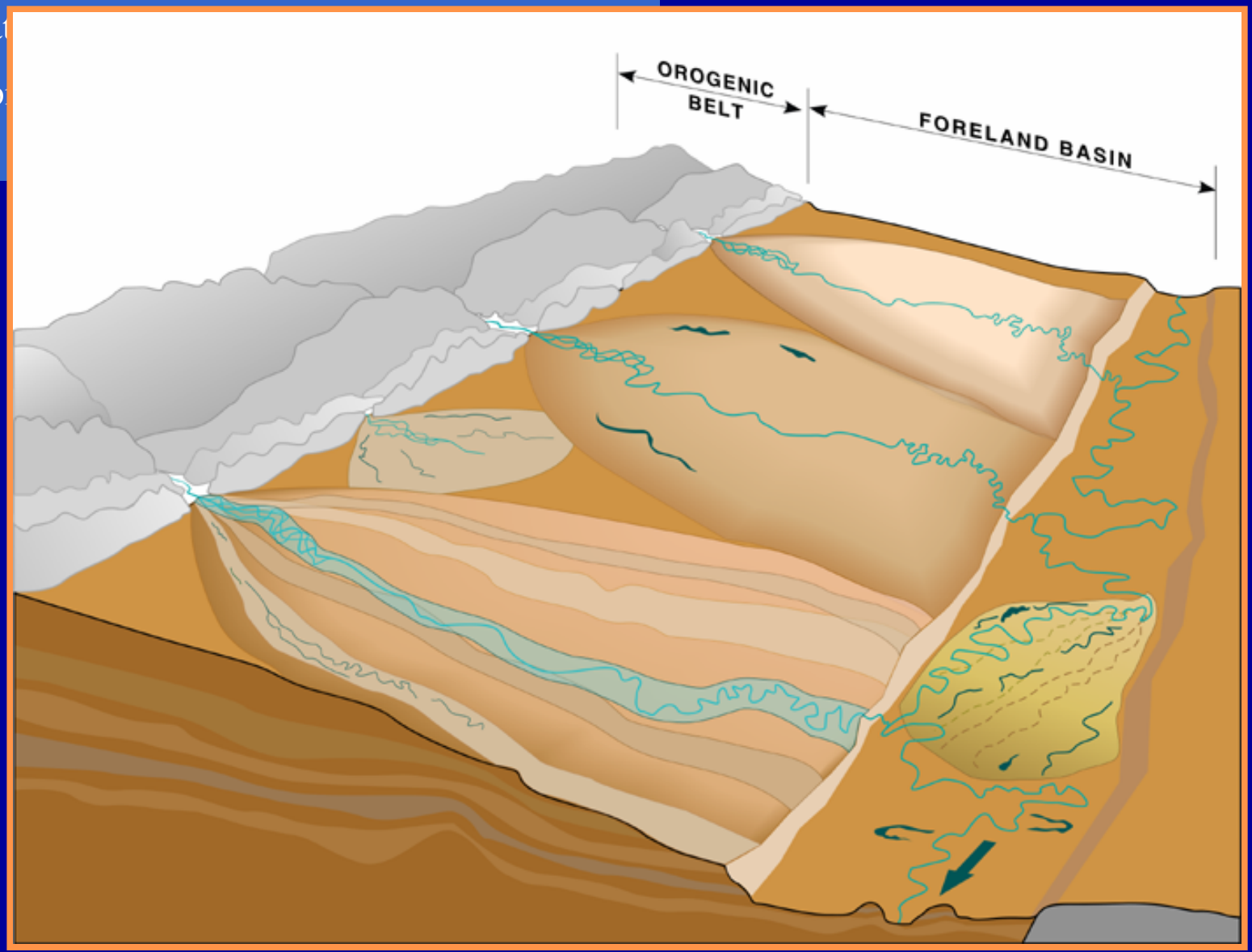
> floodplain almost without meander scars

Science Result uplinked to crew

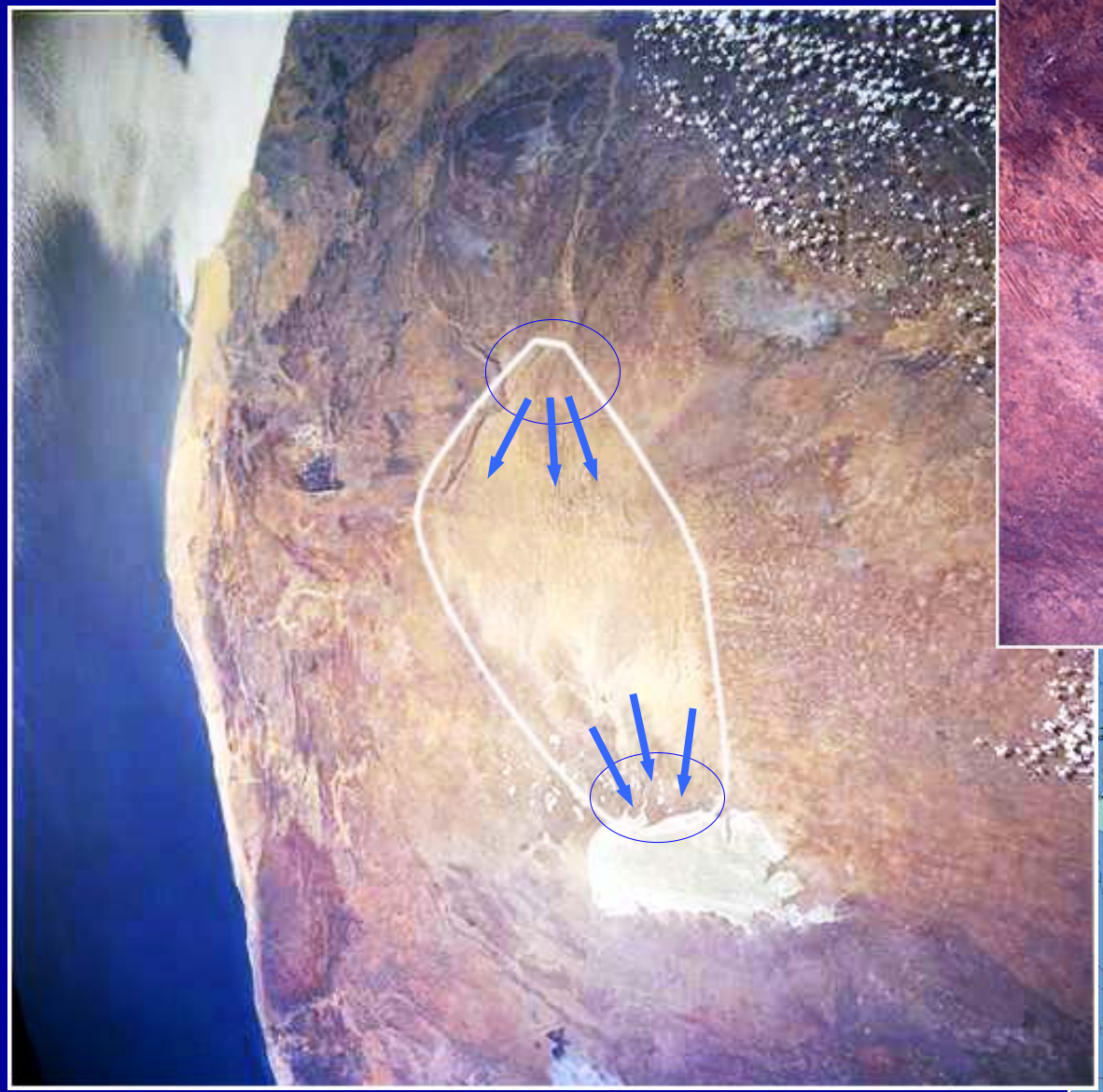
E14300, -14301, -14303, 400 mm, 20 Jan 2005

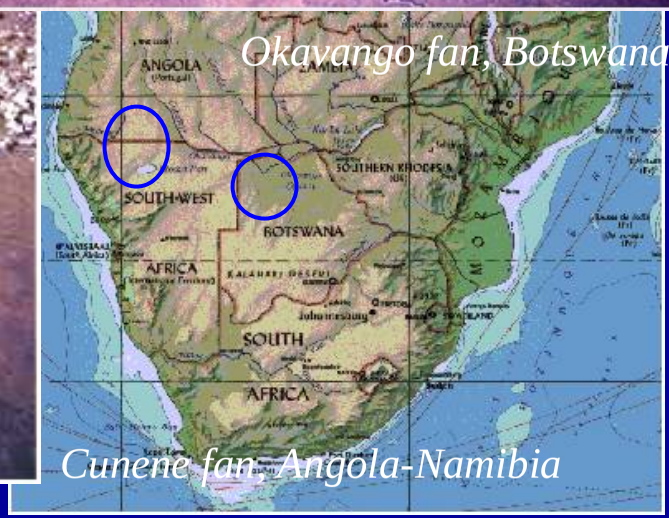
Exploration — Channel *focus points* —

- at
- p



Exploration — Focus points and *fan shape* —



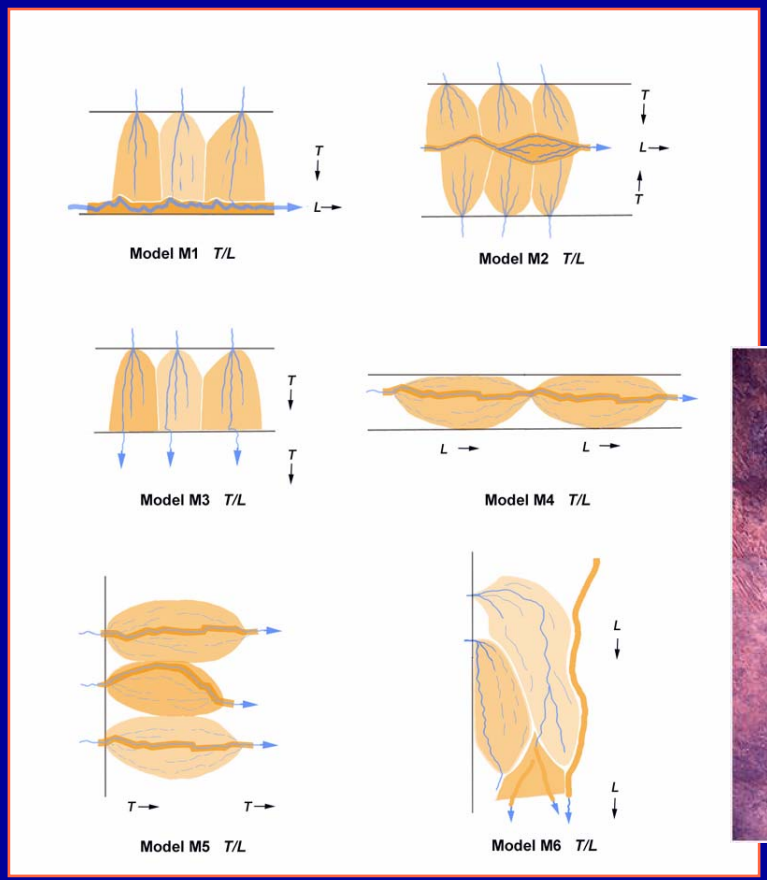


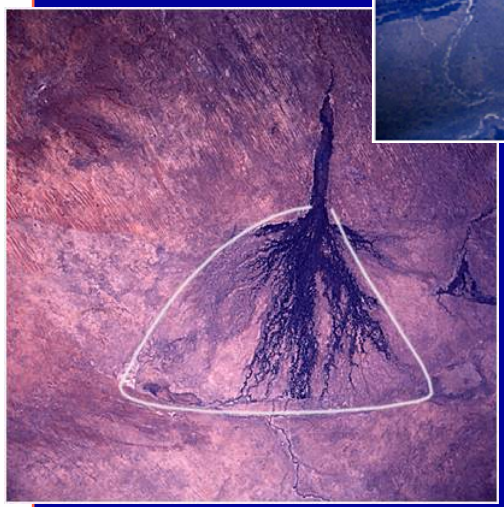
Okavango fan, Botswana

Cunene fan, Angola-Namibia

Exploration — shape relates to *nesting patterns* —

- *fan shape*
- *"space sharing phenomenon" — crowding out alluvial fans*
- *basics of paleogeography*

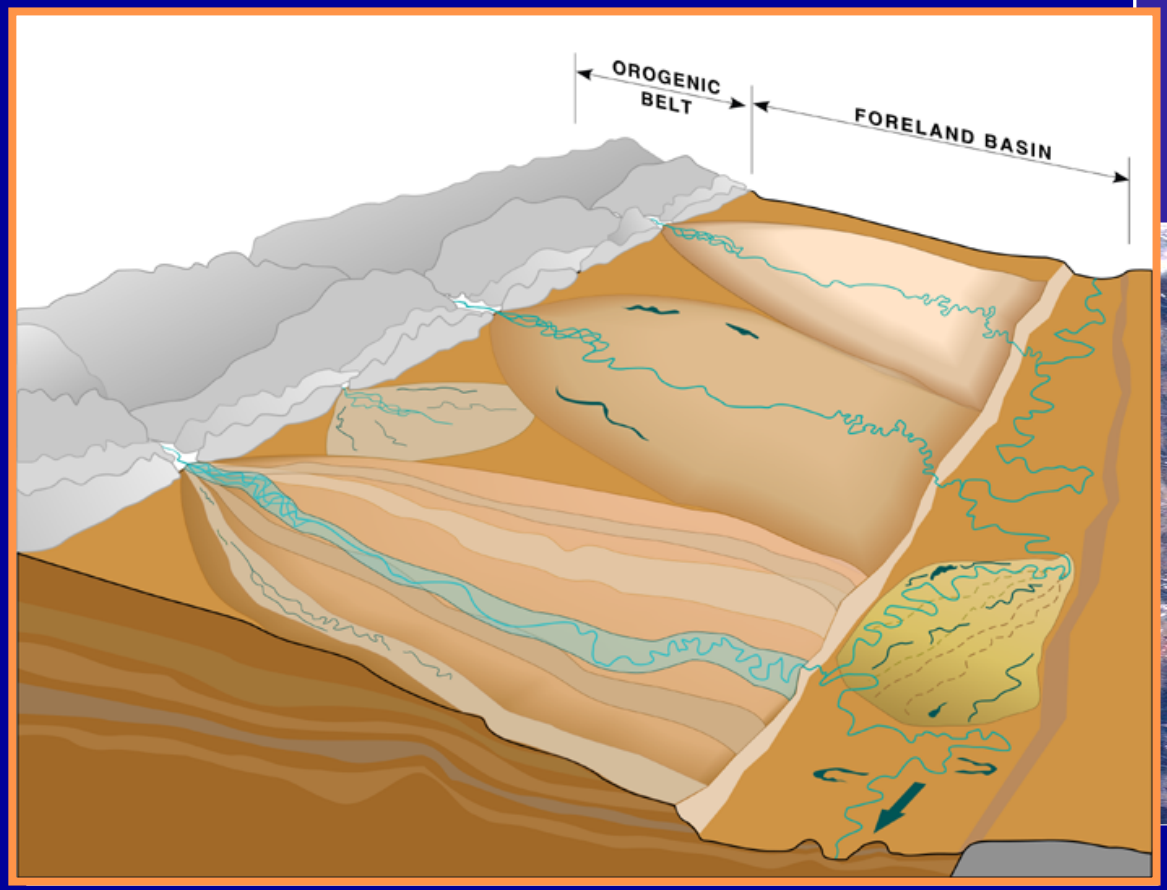


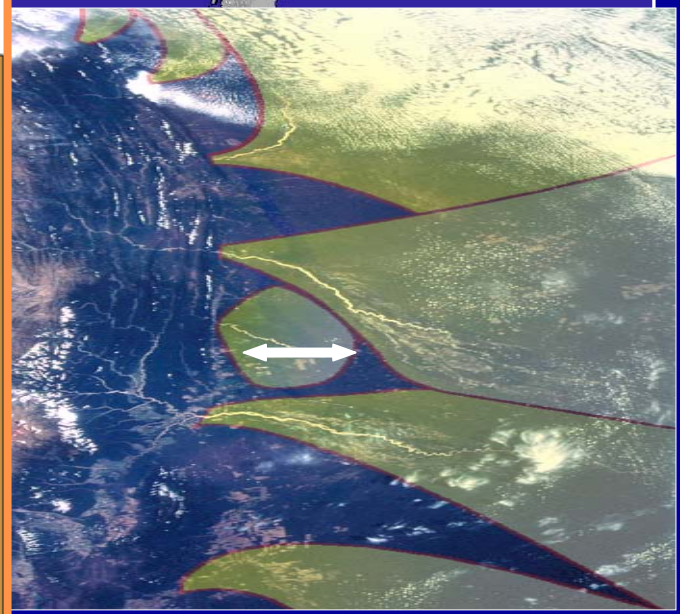


Exploration —

nesting patterns —

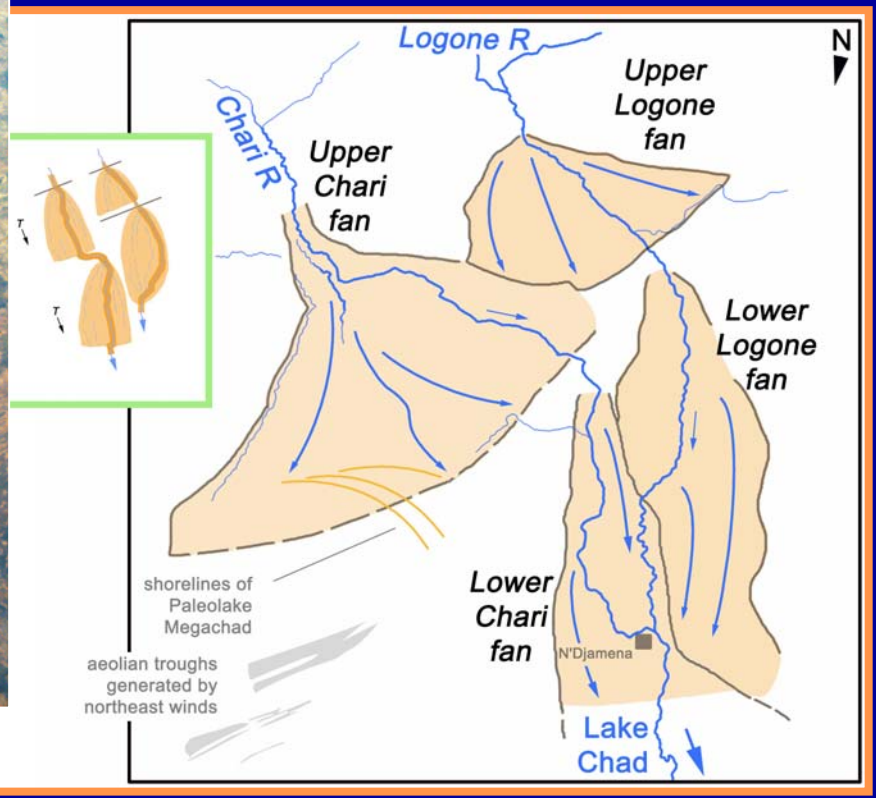
Contiguous megafans cover
> 1.2m km^2 in S America





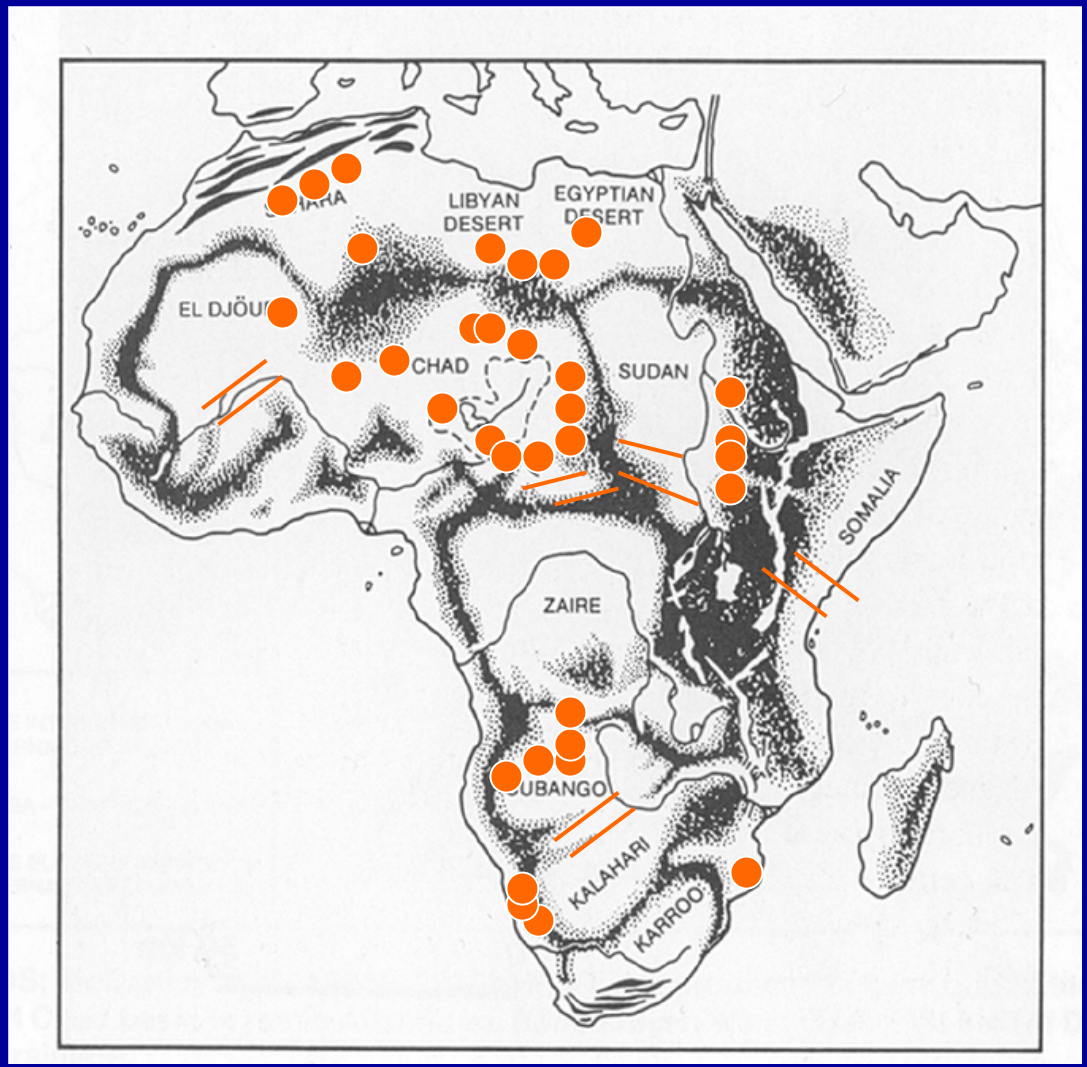
Exploration —

nesting patterns —



Logone & Chari megafans, Chad

Exploration — *nesting patterns* —



Basin-and-swell topography — double- and single-margin basins

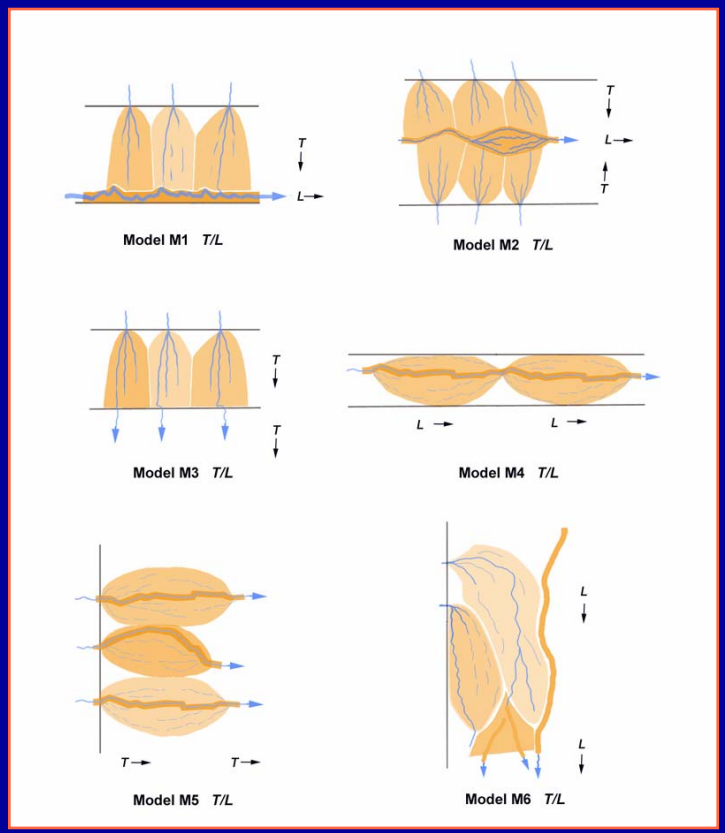
- double-margin basins —
  - most fans and fan clusters within rifted lowlands
  - triangle-shaped fans more frequent
- single-margin basins —
  - fan distribution along basin circumferences
  - large fans at variable altitudes
    - on swell flanks mainly
    - sometimes on basin floors
    - sometimes on swell crests !

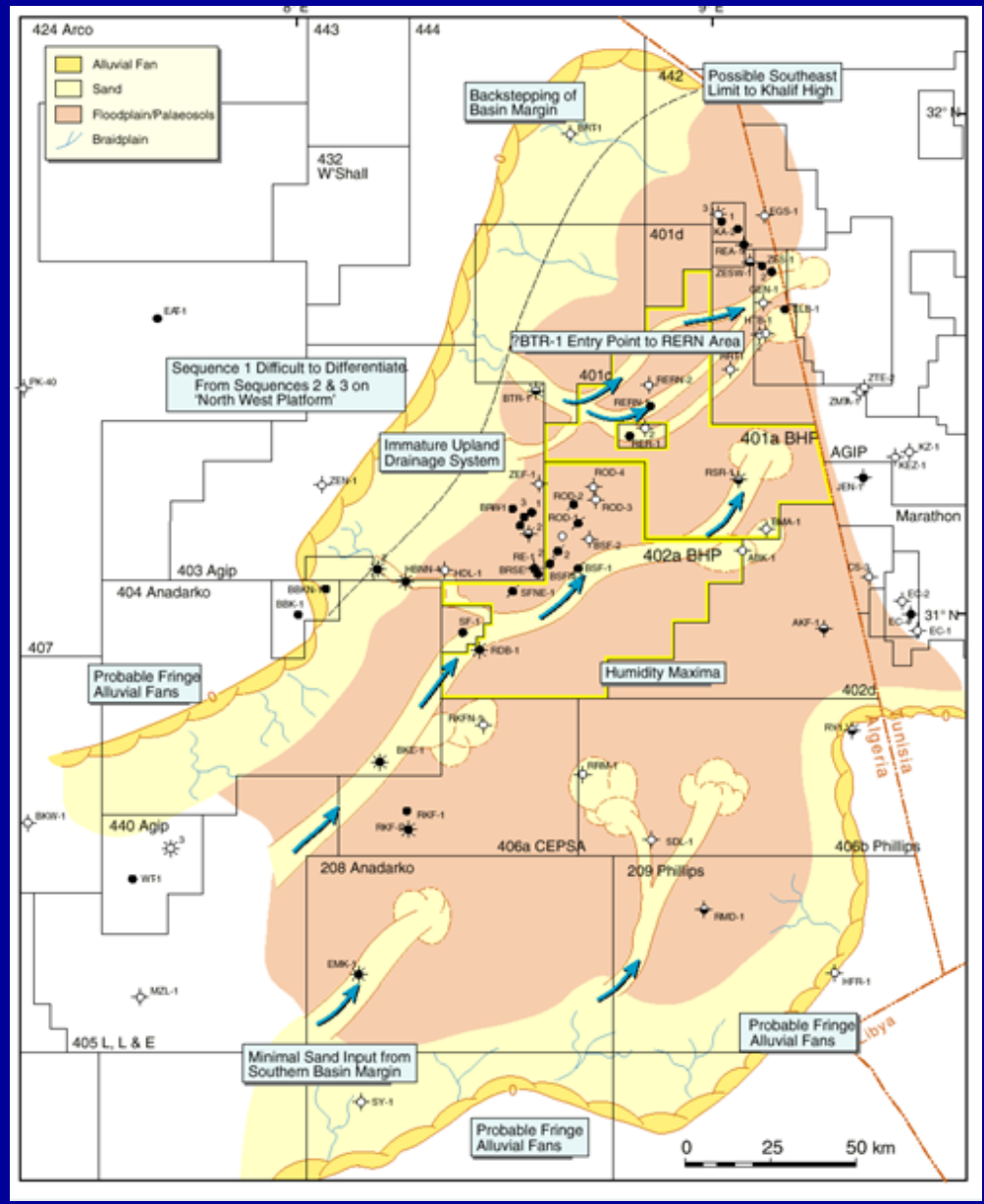
    larger sample required
  - diamond-shaped fans more frequent
  - clusters of fans in the T/T pattern

Exploration —

Paleogeography —

Late Triassic Berkine basin, Algeria —





Turner 2001

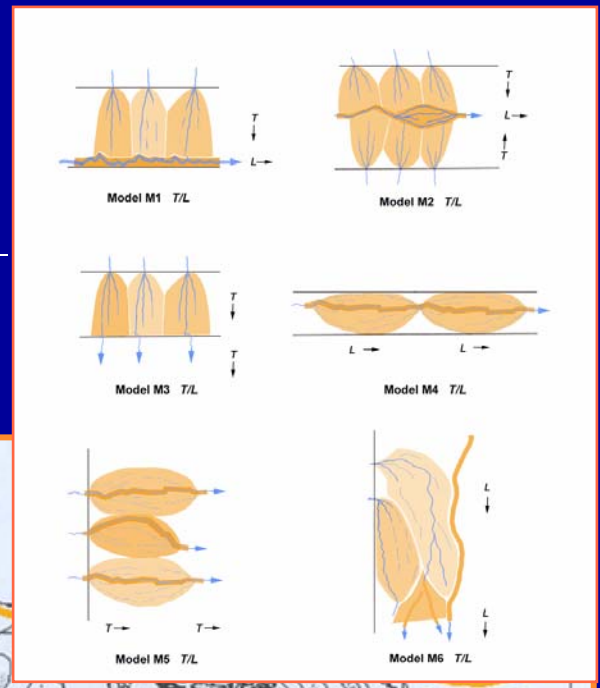
Exploration —

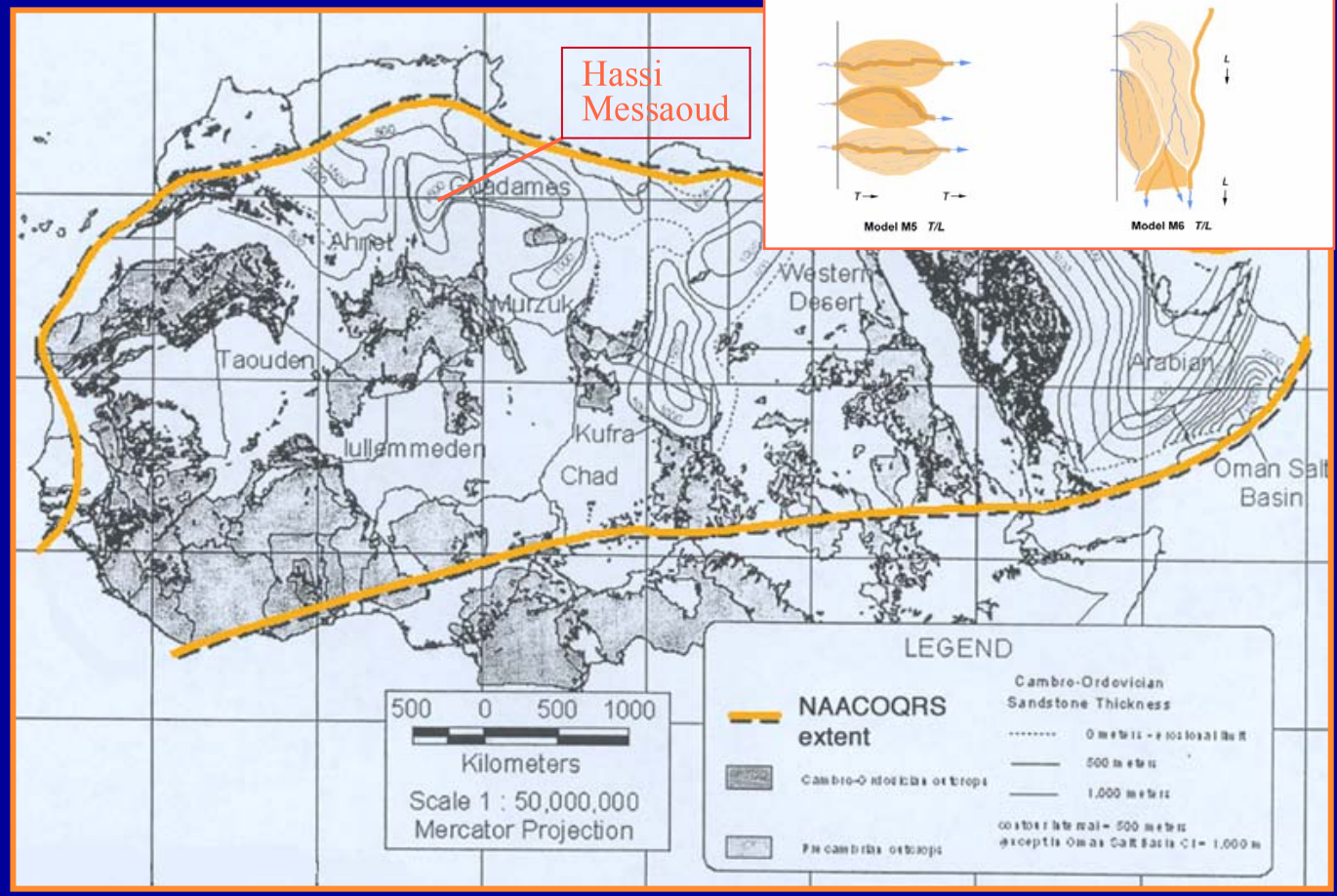
Paleogeography —

Largest known sandstone on Earth, with major plays —

North African and Arabian Cambro-Ordovician Quartz-rich Sandstones (NAACOQRS), Sahara and Saudi Arabia

- with significant hydrocarbon deposits
- *New theory: NAACOQRS probably composed of a series of multiple megafans*

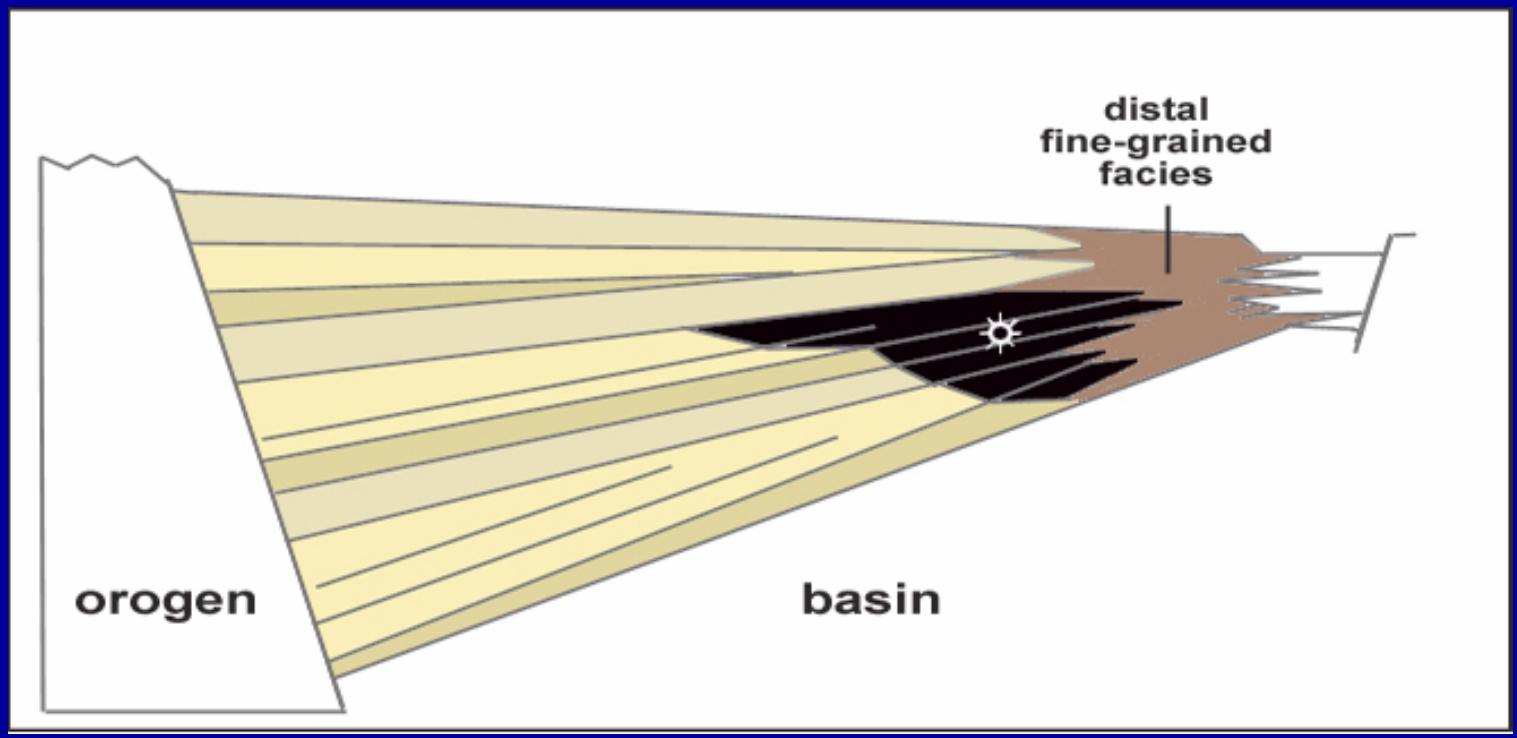




from Burke et al., 2002

Exploration —

Stratigraphic traps and megafans —



stacked megafans
hundreds of km in radius
thousands of metres in depth

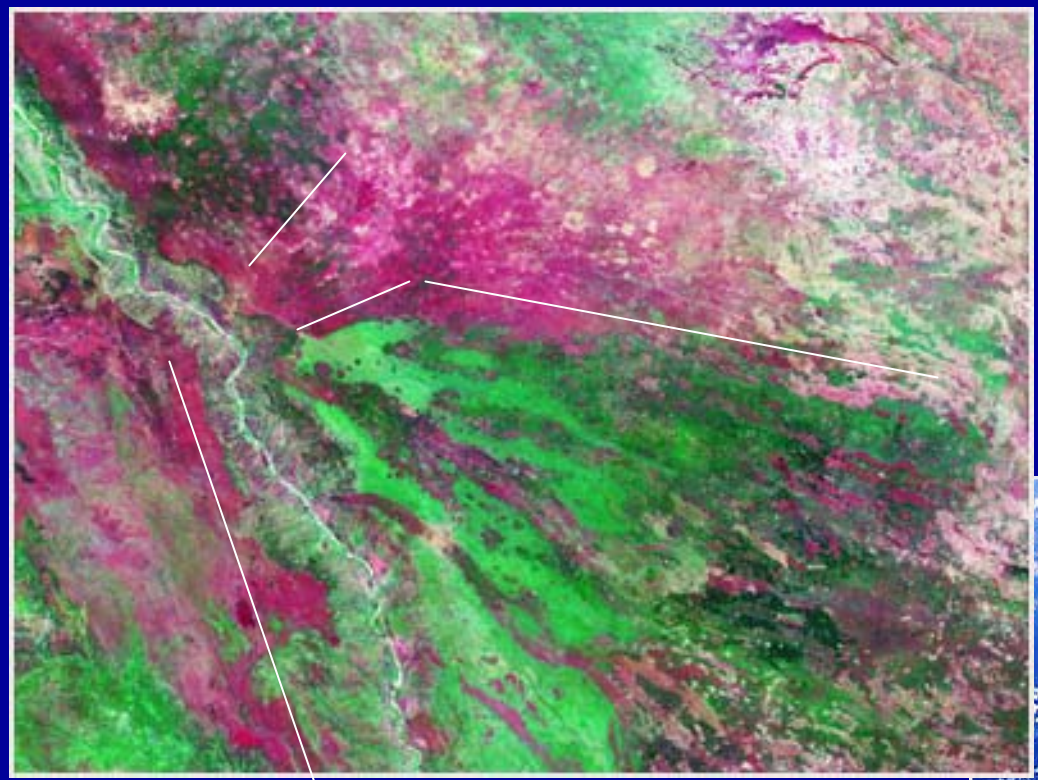
Exploration —

Coastal megafans —

Gulf of Mexico, looking east
Astronaut image STS41C-51-241

Coastal megafans —

Save and Limpopo River megafans,
Mozambique —



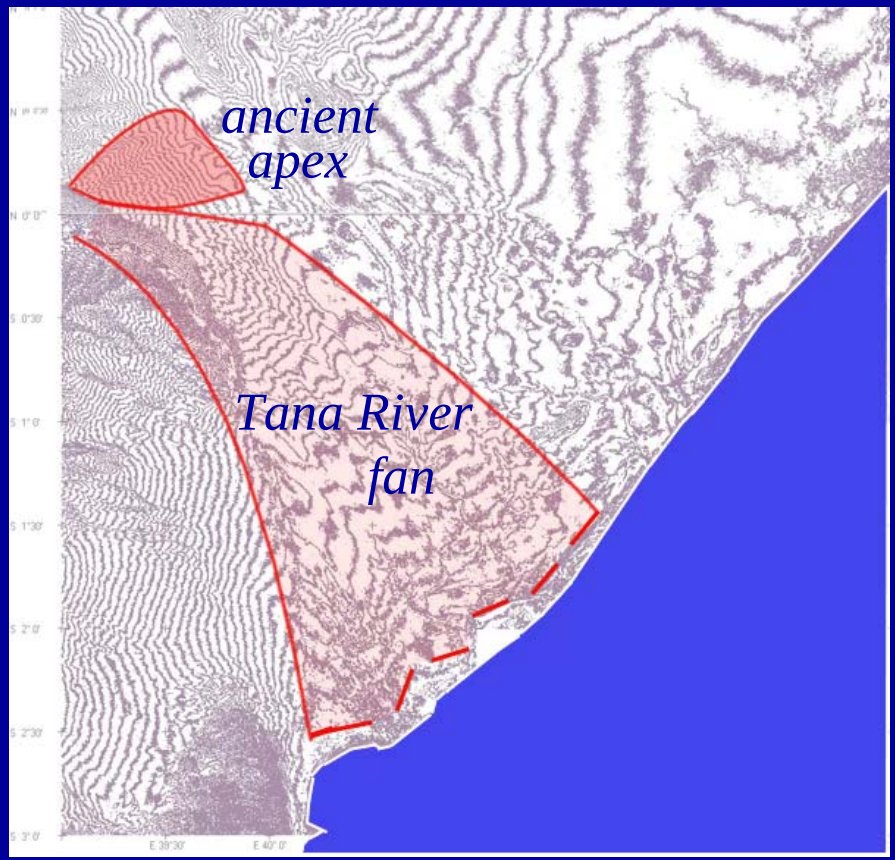
Pande & Temane
gas fields

Astronaut image
STS55-151-20

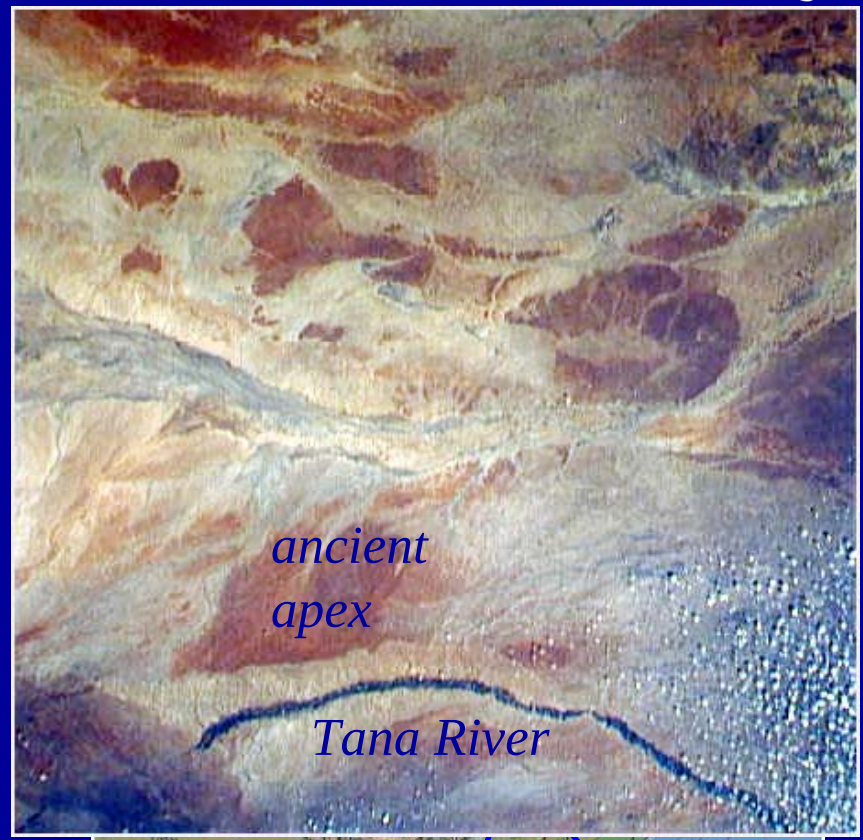
Coastal megafans —

Tana River megafan —

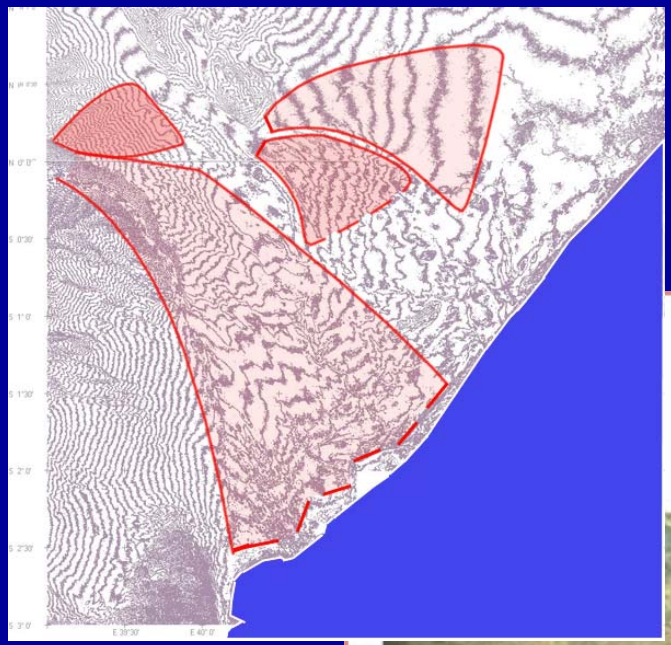
Topography — SRTM mosaic
(Shuttle Radar Topography Mission)



Astronaut handheld images



Lak Dera megafan —



SRTM mosaic (Shuttle Radar Topography Mission)

Juba River

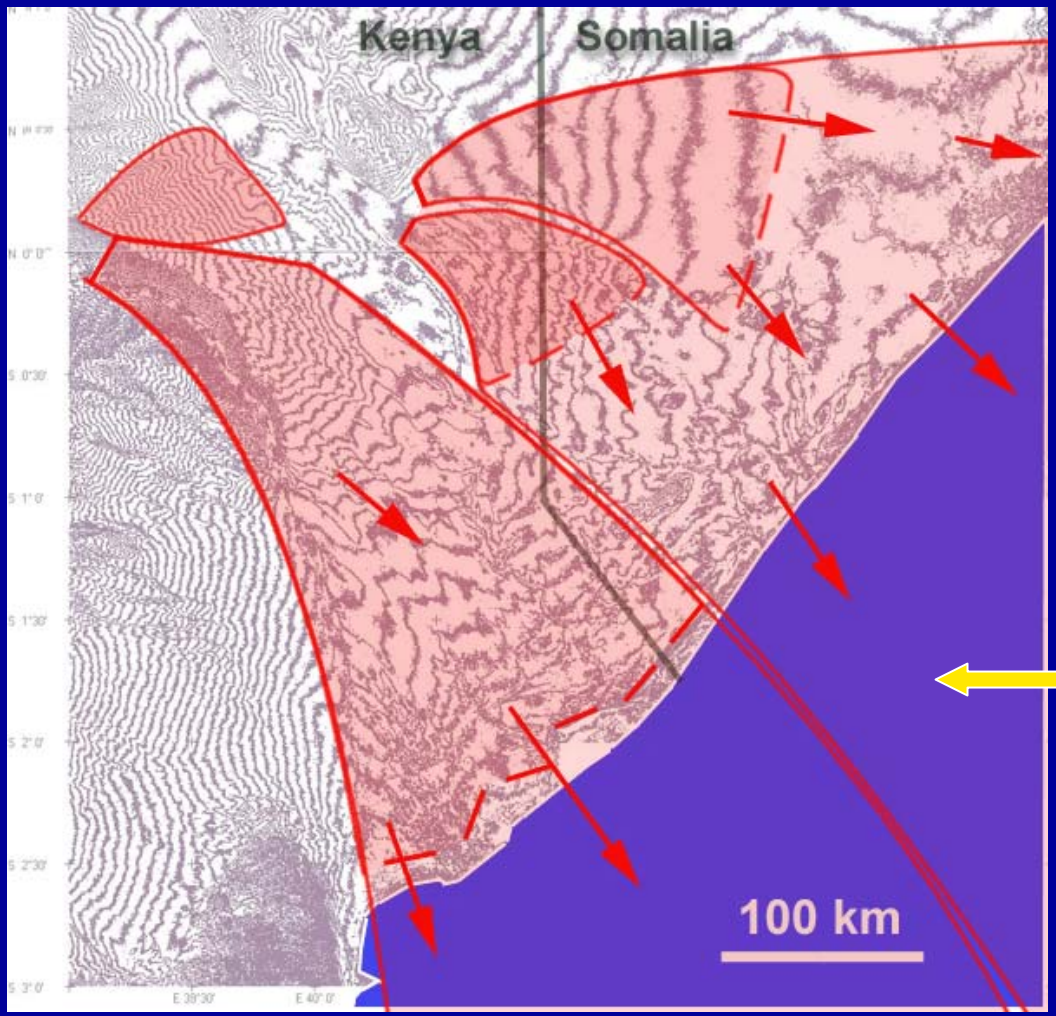
Astronaut imagery mosaic

modern fan

ancient apex

Astronaut images STS61C-46-66, 67, 68, STS41B-33-1360

Paleogeographic implications —



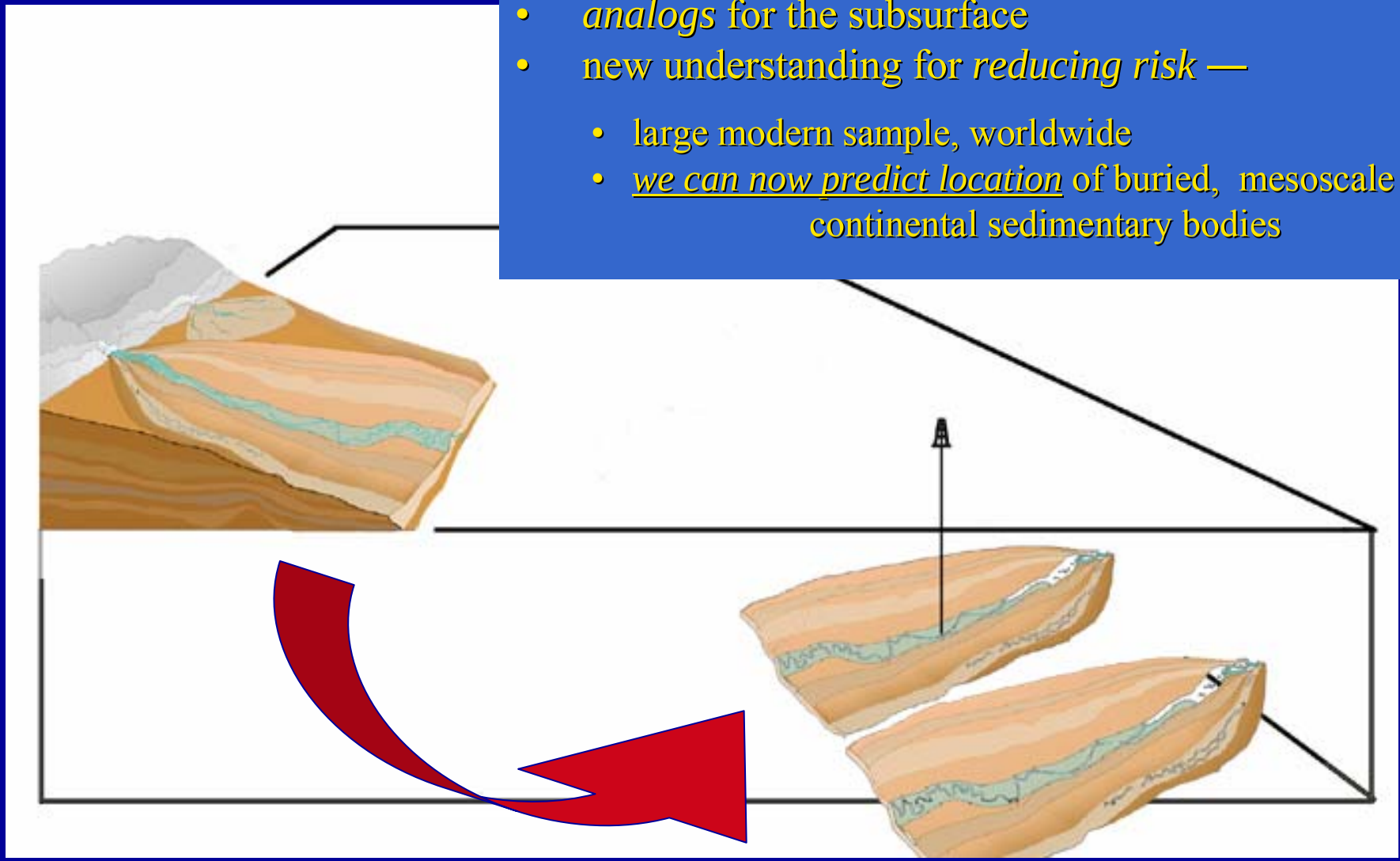
- megafan rivers *commonly* hundreds of km long
- megafans *probably* extend offshore
- sweep angles need to be considered

Oil slick off southern Somalia — sunglint view from Space Shuttle

Conclusions —

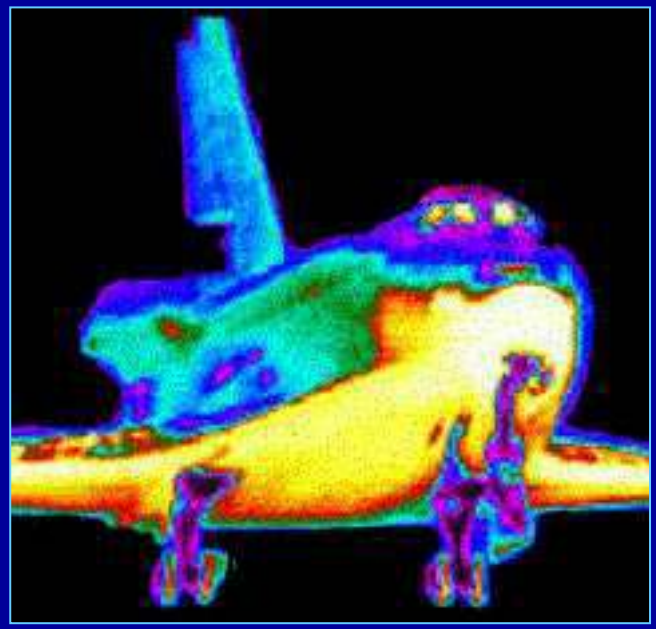
modern megafans —

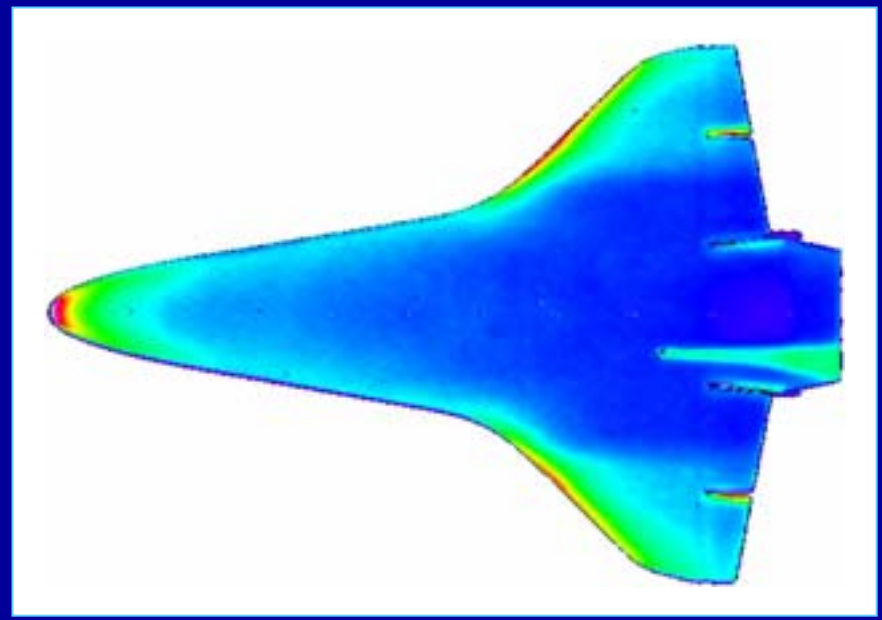
- *analogs* for the subsurface
- new understanding for *reducing risk* —
  - large modern sample, worldwide
  - *we can now predict location* of buried, mesoscale continental sedimentary bodies

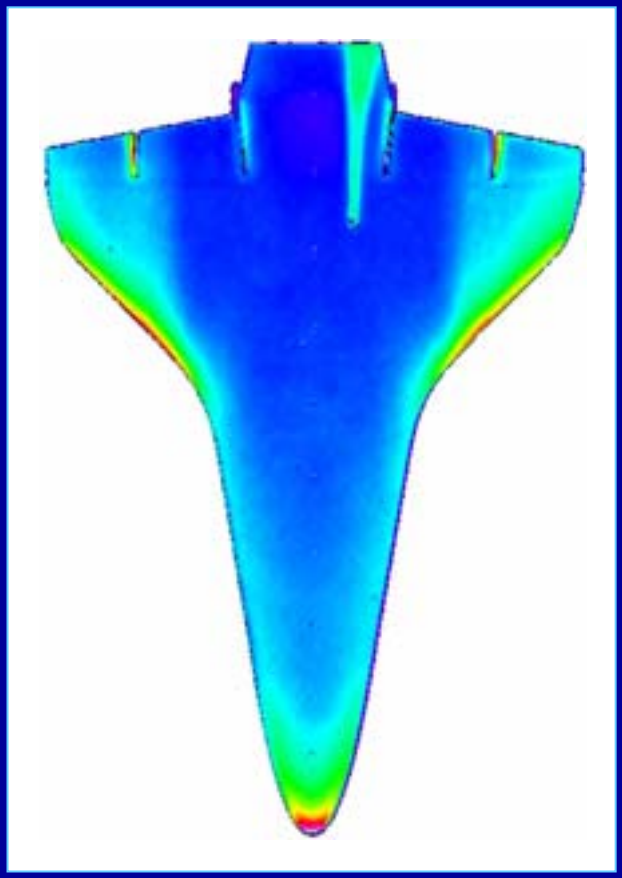


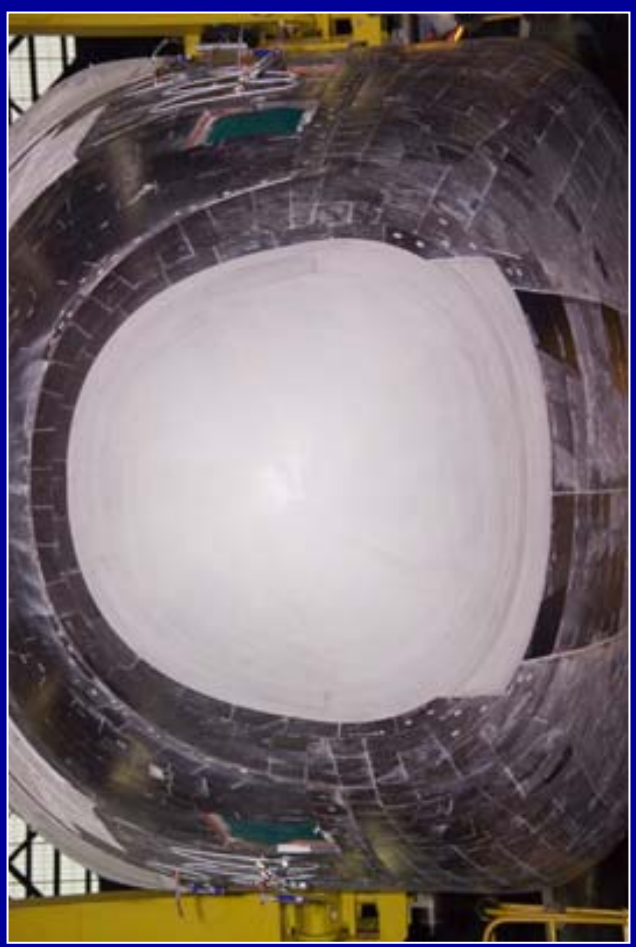

NASA/IPAC

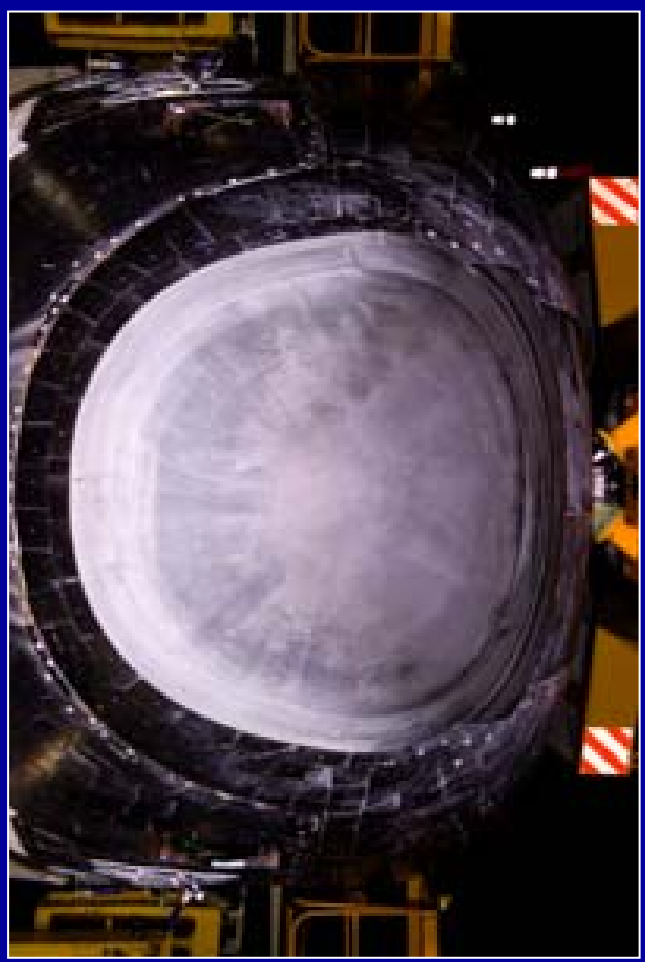

United States
6











In memory of the crew of
Space Shuttle *Columbia*, STS-107…