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Climate Change Impact on Past Civilizations: Lessons from Space Data and Archaeology……the Younger Dryas and After…

Ronald Blom *Jet Propulsion Laboratory, California Institute of Technology*

With contributions from many colleagues, especially:

Bruce Chapman, Bob Crippen, Joan Feynman, Bill Patzert, Veronica Nieves, Alexander Ruzmaikin, and Josh Willis

Jet Propulsion Laboratory, California Institute of Technology

Damian Evans and Roland Fletcher *University of Sydney, Australia*

Dan Irwin *NASA Marshall Space Flight Center*

Sarah Parcak *University of Alabama Birmingham*

Tom Sever *University of Alabama Huntsville*

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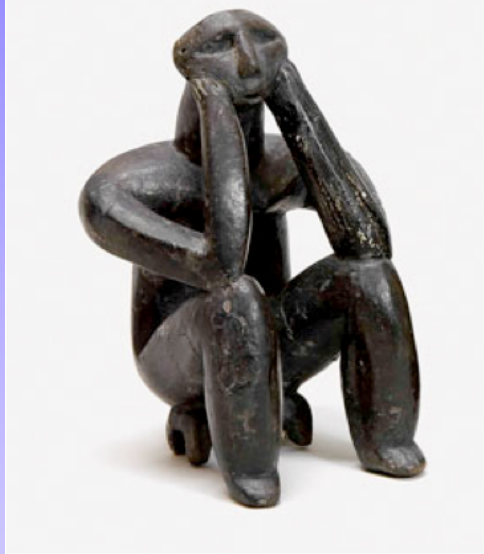

We got stuff to think about……..

"The Thinker" ~5000 BCE

Figurine from Hamangia, Cernavodå
National History Museum of Romania, Bucharest

Photo: Marius Amarie. New York Times, November 30, 2009
"A Lost European Culture, Pulled From Obscurity" John Noble Wilford

We are on a climate change adaption path. Minor past climate changes have resulted in significant social disruption, what can our ancestors teach us?

- **End of Younger Dryas and dawn of agriculture**
- **Western Desert of Egypt-Neolithic in now hyperarid terrain**
- **Old Kingdom of Egypt-doomed by drought?**
- **Maya decline/collapse-drought and deforestation**
- **Angkor Wat-Megalithic structures and water control-drought and decline**

What will be different this time?

We can see it coming-lots of data our ancestors didn't have

We have science-a method our ancestors didn't have

2nd Polar Shipping Summit

30 - 31 March 2011 Montreal, Canada

ACI

Prices and Payment Information

Summit (Includes Documentation Packet)	**30th and 31st March 2011**	**£1,495**
Documentation Packet	Copies of all Summit Proceedings	£420

Documentation Packet Available

You can purchase the **Polar Shipping** papers at just £420. Simply tick the box on the booking form, send it with payment and your copy will be on its way to you after the meeting. This important manual will be a source of invaluable reference for the future.

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ARCTIC PORTAL

Alan Robock
Department of Environmental Sciences

This event has passed.

7th Arctic Shipping Summit

Date: 11th November 2015 - 12th November 2015 **Location:** London - UK

Identifying Profitability In Arctic Shipping With Safe & Efficient Operations

ACI's 7th Arctic Shipping Summit 2015 will focus on discussing the practical solutions necessary for the ship owners to decide whether they should invest in utilising the Northern Sea Route. The meeting will provide updates on key developments and regulations in the Arctic, as well as present expert views on possible future advances in governing the transport routes.

The conference will also address how to overcome the operational challenges that exist while entering the region. These include navigation, communications, risk and safety management, search and rescue, vessel design and crew training. The meeting will provide an outlook for the recent innovations in ice class vessel design as well as updates on ice breaker technology.

Joining the Summit will allow participants to better understand and evaluate the business model for operating in the Arctic.

Climate Stability is a Key Factor

In the Development of Agriculture and Complex Societies

Consider:

- Anatomically modern humans in Africa about *130,000 years ago*
- Humans migrate out of Africa during wet phases perhaps as early as ~120,000 years ago, but significant about *55,000 years ago*
- Stunning art and culture in Europe and Indonesia by about *30,000 years ago*
- BUT, no agriculture and no complex societies until *about 11,000 years ago*
- Therefore, ~120,000 years of human pre history with no agriculture or complex societies
- WHY?

Chauvet Cave Art

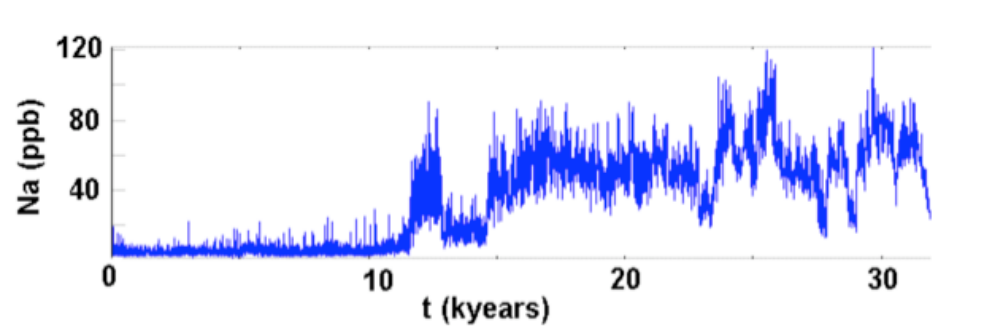
H. Valladas, J. Clottes, et al., Nature, 2001
See also National Geographic August 2001

Climate Stability is a Key Factor

In Development of Agriculture and Complex Societies

What happened?

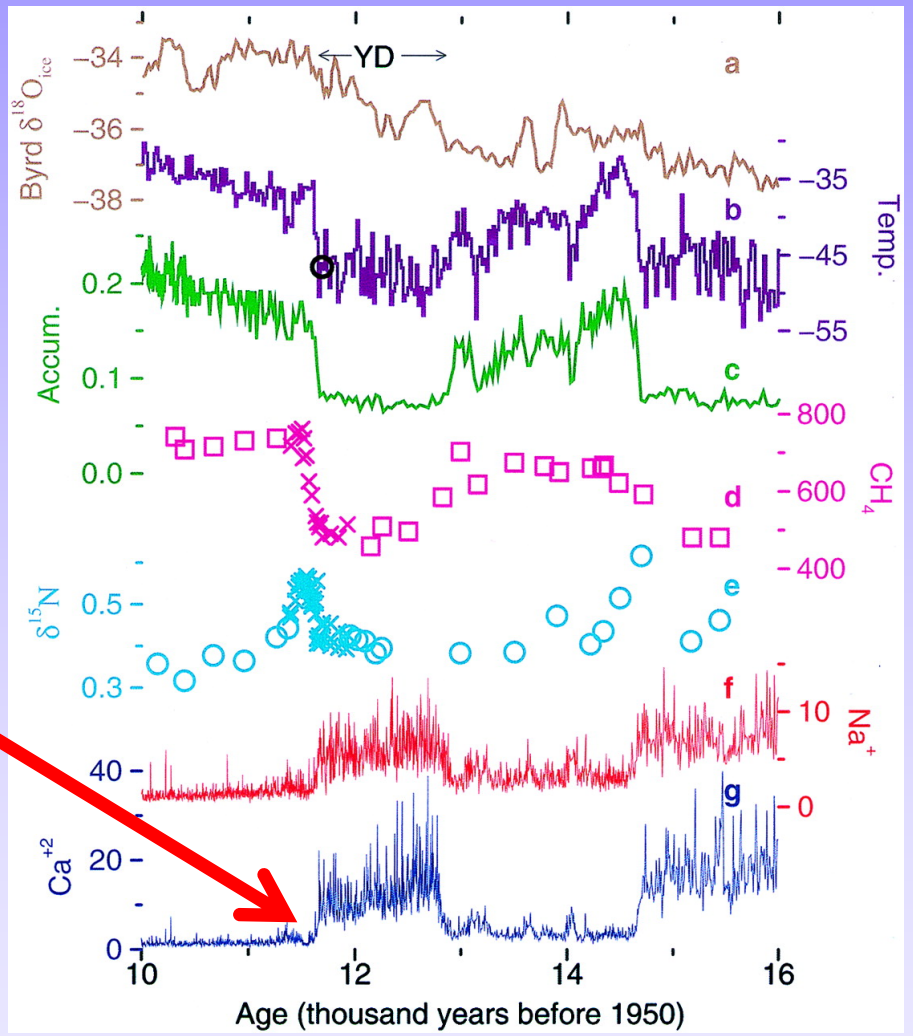
- Various measures of climate show relatively sudden broad stabilization



- Plot of Na concentration in Greenland ice core GISP 2
- Na proxy for wind and storms
- Climate becomes much more stable at end of Younger Dryas, 11,570 (+/- 200) years ago (Hughen, et al., Science 2000)
- Sea level also stabilizes, but now increasing from ~2 to > 3mm/yr

High-resolution data from the GISP2 ice core, Greenland, and the Byrd ice core, Antarctica, covering the Younger Dryas interval (YD) and adjacent times, modified slightly from ref. 37.

For the best-characterized warming, the end of the Younger Dryas cold interval ≈11,500 years ago, the transition in many ice-core variables was achieved in three steps, each spanning ≈5 years and in total covering **≈40 years**. Taylor, K. C. et al, et al.(1997) *Science* **278**:825–827.

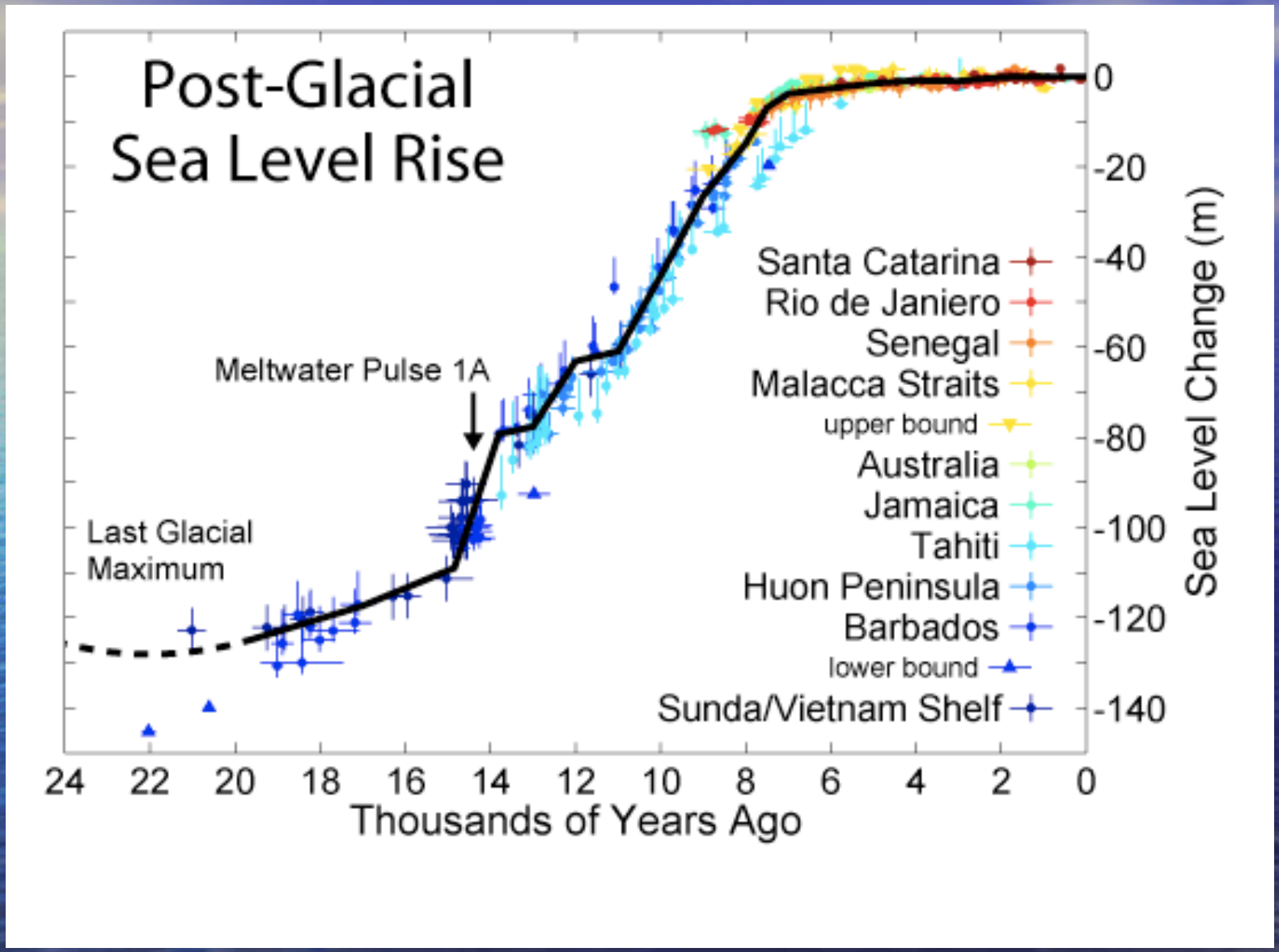


Something important happens here

Alley, R. B., 2000, Ice-core evidence of abrupt climate changes: PNAS 1331–1334, doi: 10.1073/pnas.97.4.1331

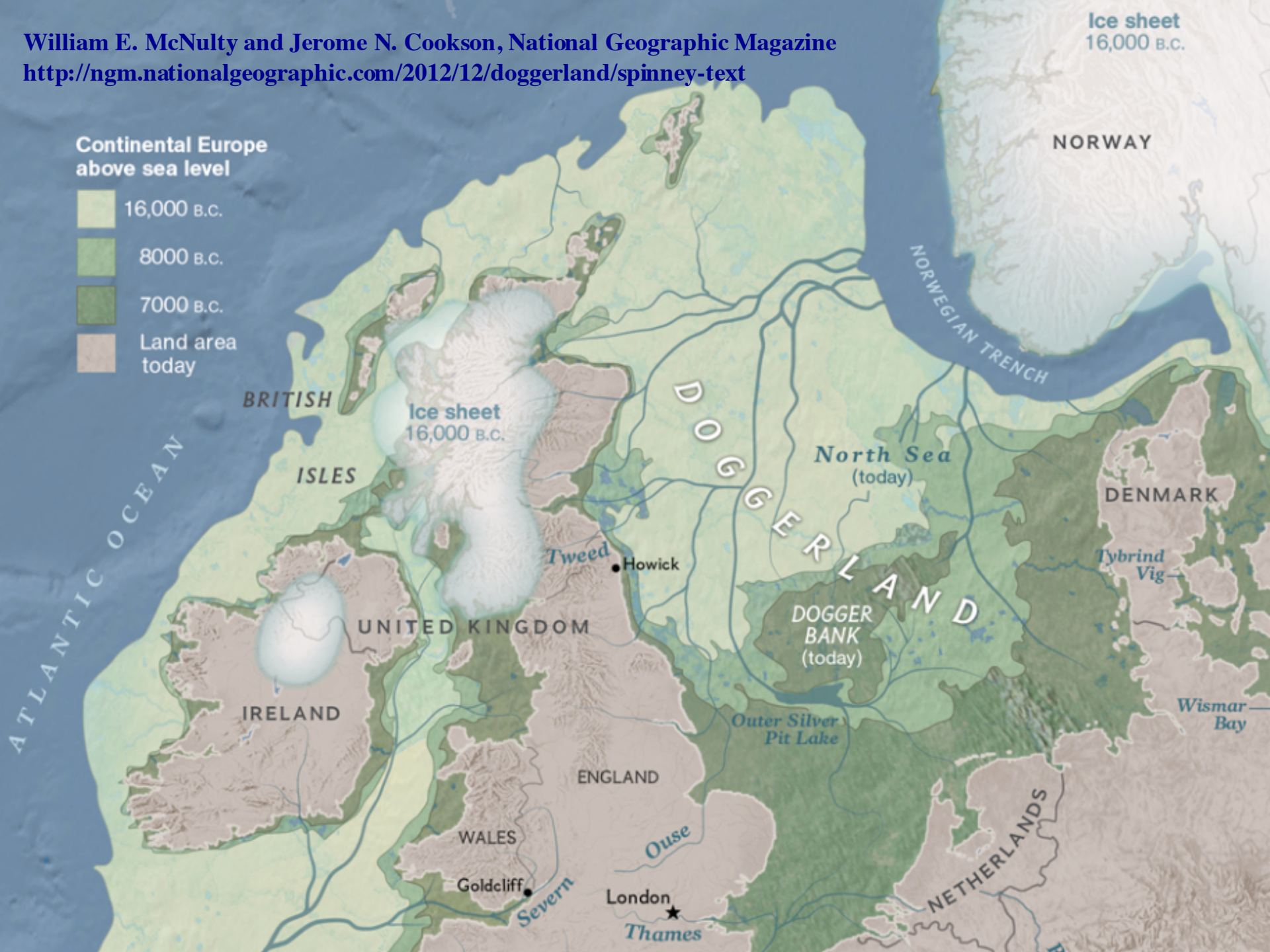
Richard B. Alley PNAS 2000;97:1331-1334

Sea Level Rise

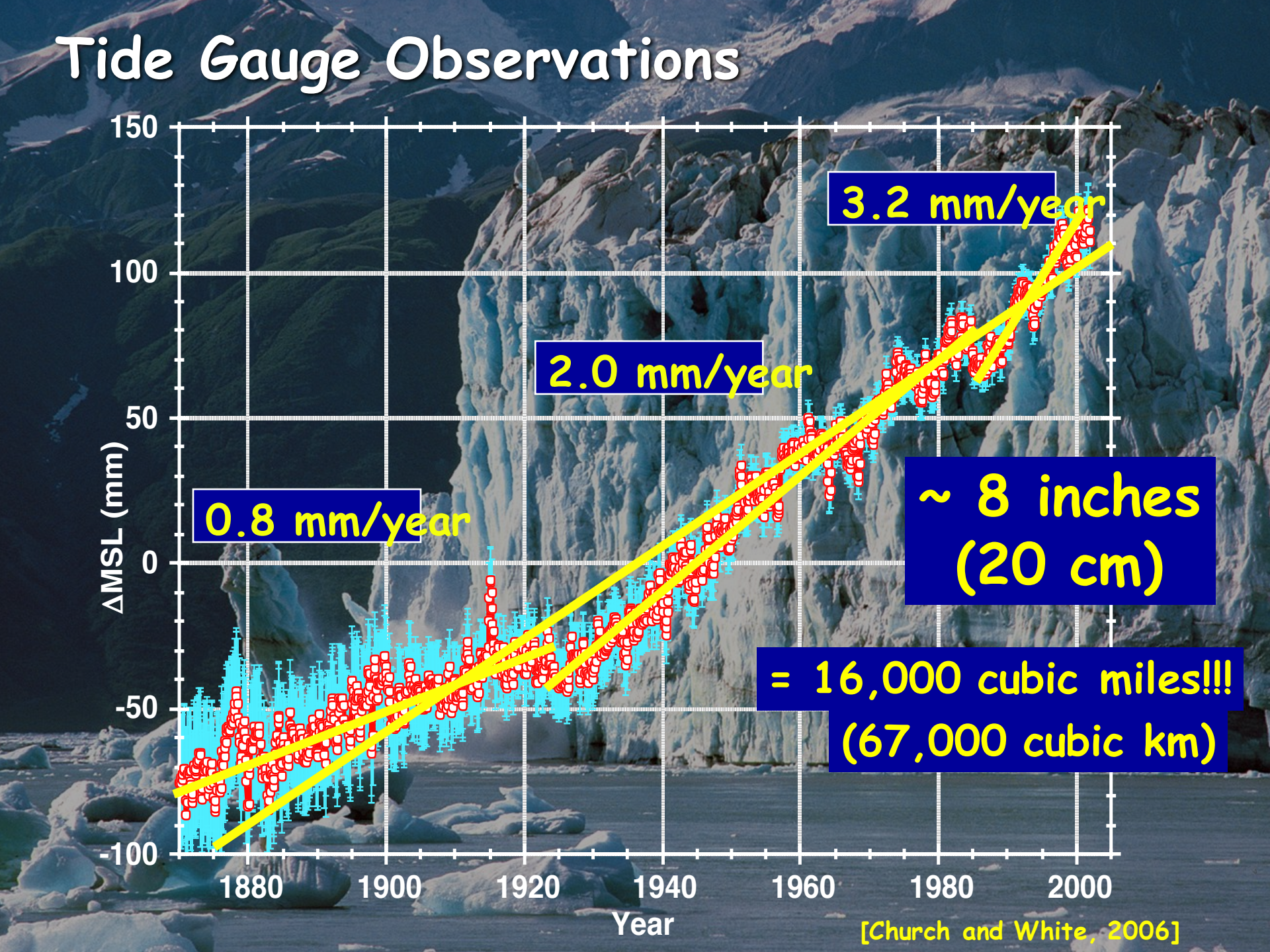


Plots by Robert A. Rohde for
Global Warming Art: http://www.globalwarmingart.com/

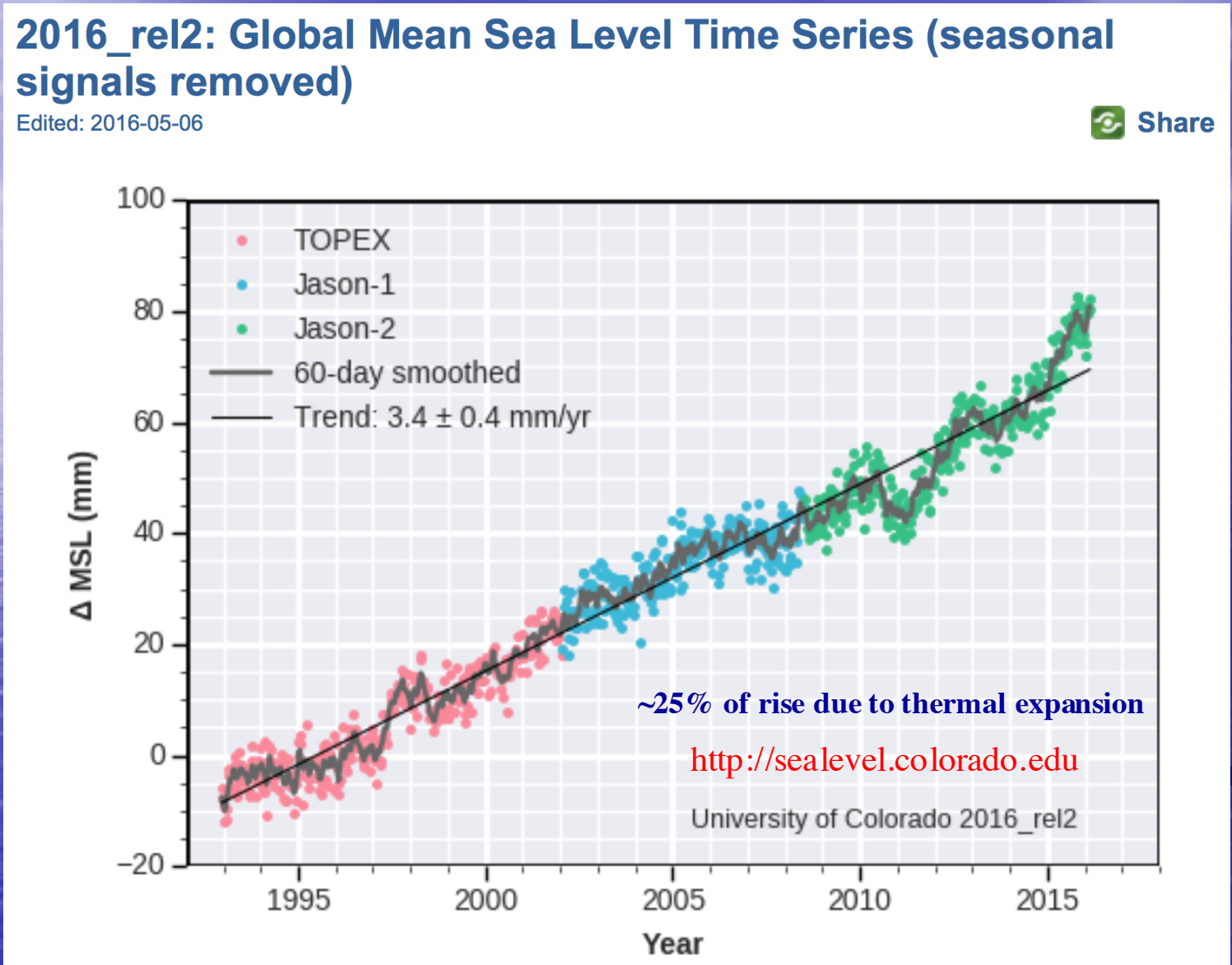
William E. McNulty and Jerome N. Cookson, National Geographic Magazine
http://ngm.nationalgeographic.com/2012/12/doggerland/spinney-text



Tide Gauge Observations



Sea Level Rise from Satellites



on

http://climate.nasa.gov/keyIndicators/index.cfm#seaLevel

Climate Stability is a Key Factor

In Development of Agriculture and Complex Societies

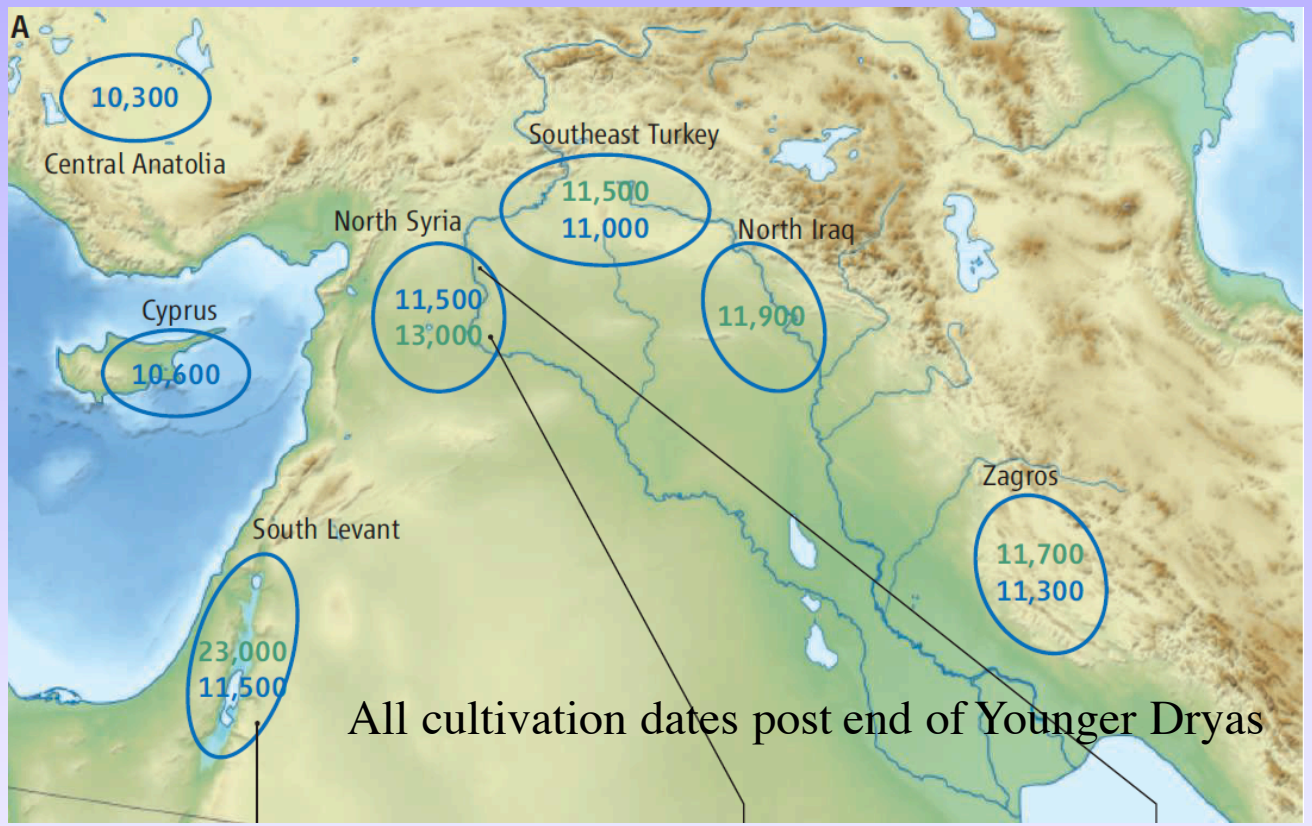
- The stable climate at the end of the Younger Dryas ~11,570 years ago was new to humans
- Long term stability allowed multiple independent agricultures and animal domestications to develop (Piperno & Pearsall, Academic, 1998; Feynman & Ruzmaikin, Climate Change, 2007)
- Agriculture and complex societies need a few decades of stability to get organized

Place	Species	Starting (ybp)
Levant	wheat, legumes, sheep	10,500
China	rice, millet, pig, silkworm	9,500
Meso-america	maize, beans, squash, turkey	9,000
Andes & Amazonia	squash and gourds	10,000
Eastern US	sunflower, goosefoot	by 4,500

Summarized from
Feynman and Ruzmaikin, 2007

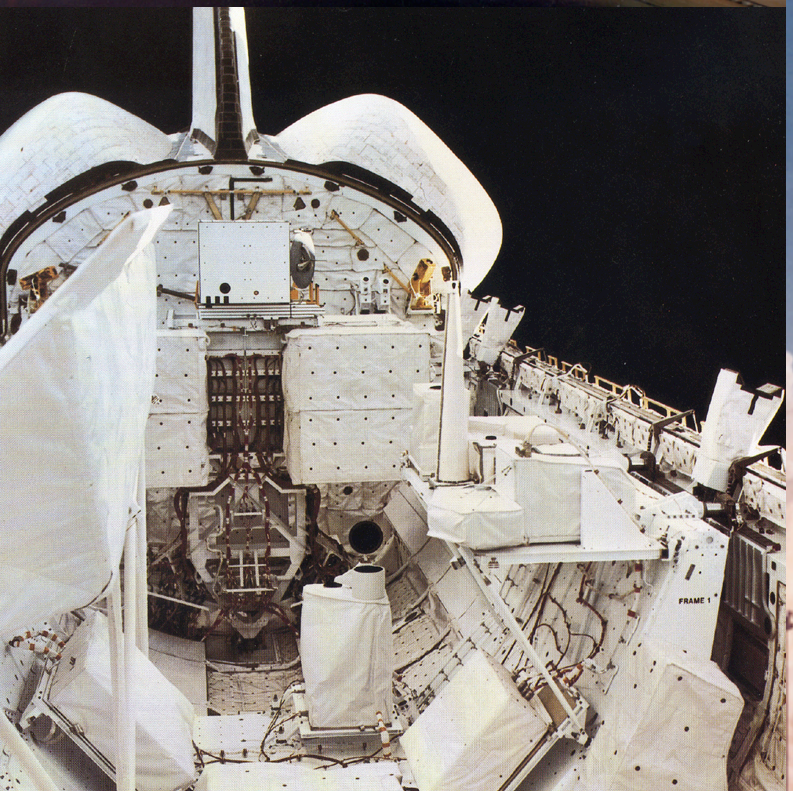
Climate Stability is a Key Factor

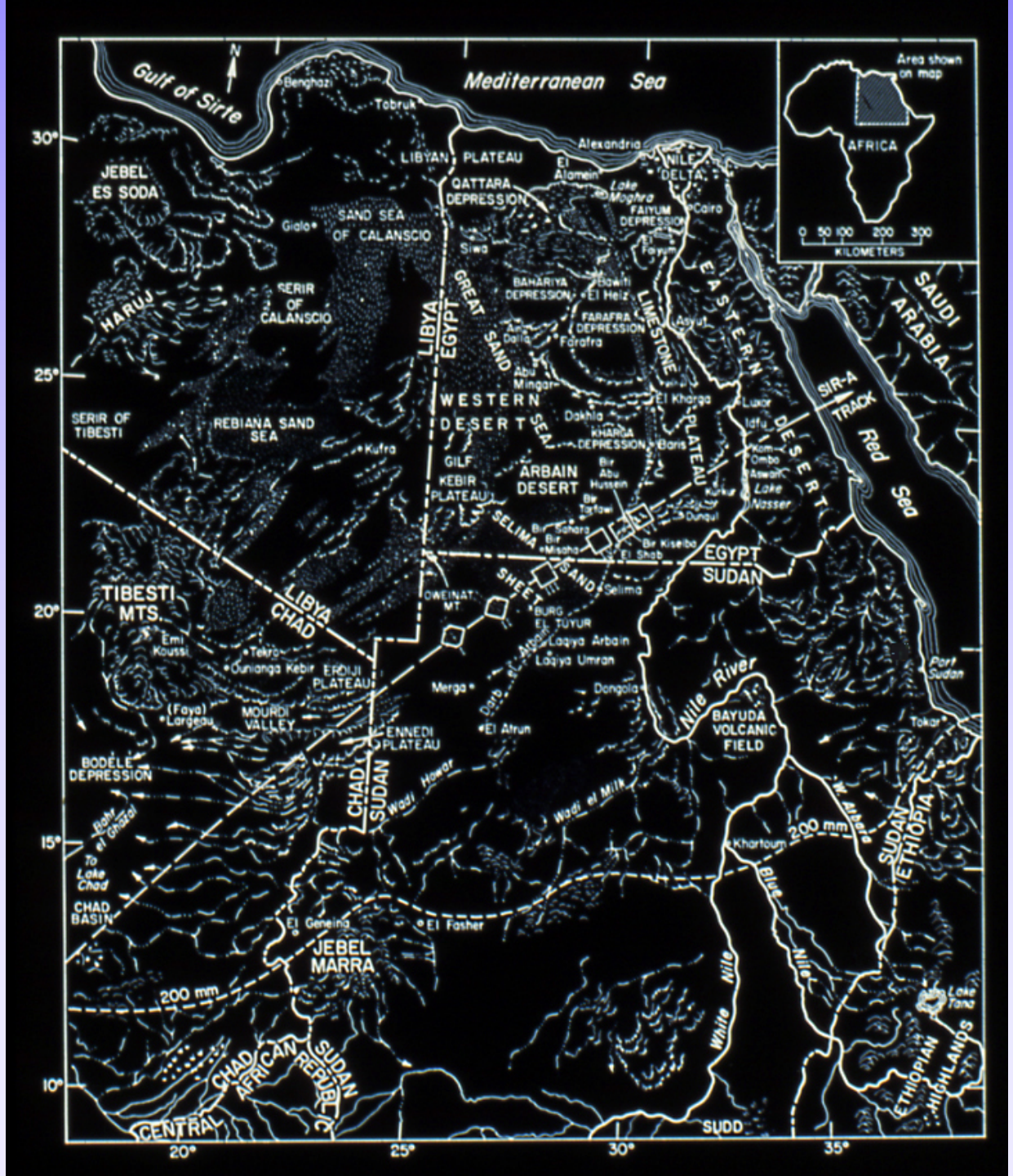
In Development of Agriculture and Complex Societies



- Green dates use without cultivation.
- Blue dates are first evidence of large scale cultivation, all < 11.5K or younger.
- From: Wilcox, G., 2013, The Roots of Cultivation in Southwestern Asia: Science, v. 341, p. 39.
- End of Younger Dryas, 11,570 (+/- 200) years ago (Hughen, et al., Science 2000)

•JPL's Shuttle Imaging Radar-A flew on 2nd flight of Space Shuttle Columbia in 1981

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Mediterranean Sea
N
Benghazi
Tobruk
Alexandria
El Alamein
Lake Maghra
Cairo
NILE DELTA
FAIYUM DEPRESSION
LIBYAN PLATEAU
QATTARA DEPRESSION
JEBEL ES SODA
Gialo
SAND SEA OF CALANSCIO
Siwa
SERIR OF CALANSCIO
HARUJ
BAHARIYA DEPRESSION
Bawiti
El Heiz
FARAFRA DEPRESSION
Farafra
Asyut
EASTERN LIMESTONE PLATEAU
GREAT SAND SEA
LIBYA
EGYPT
Abu Mingar
WESTERN DESERT
El Kharga
Luxor
Idfu
SIR-A TRACK
SAUDI ARABIA
Red Sea
SERIR OF TIBESTI
REBIANA SAND SEA
Kufra
Dakhla
KHARGA DEPRESSION
Baris
DESERT
Kom Ombo
Aswan
Lake Nasser
GILF KEBIR PLATEAU
ARBAIN DESERT
Bir Abu Hussein
Bir Tarfawi
Kuka
Dungul
SELIMA SAND SHEET
Bir Sahara
Bir Misaha
Bir Kiseiba
El Shab
EGYPT
SUDAN
Selima
TIBESTI MTS.
LIBYA
CHAD
OAEINAT MT
BURG EL TUYUR
Laqiya Arbain
Laqiya Umran
Emi Koussi
Tekro
Qunianga Kebir
EROUI PLATEAU
Merga
Dongola
Nile River
Port Sudan
(Faya) Largeau
MOURDI VALLEY
EENNEDI PLATEAU
El Atrun
BAYUDA VOLCANIC FIELD
Tokar
BODELE DEPRESSION
CHAD
SUDAN
Wadi Howar
Wadi el Milk
Bahr el Ghazal
to Lake Chad
Khartoum
200 mm
Wadi el Ajjale
SUDAN
ETHIOPIA
CHAD BASIN
El Geneina
El Fasher
Blue Nile
JEBEL MARRA
White Nile
Lake Tana
ETHIOPIAN HIGHLANDS
CHAD
CENTRAL AFRICAN REPUBLIC
SUDAN
SUDD
Area shown on map
AFRICA
0 50 100 200 300
KILOMETERS
30°
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30°
35°

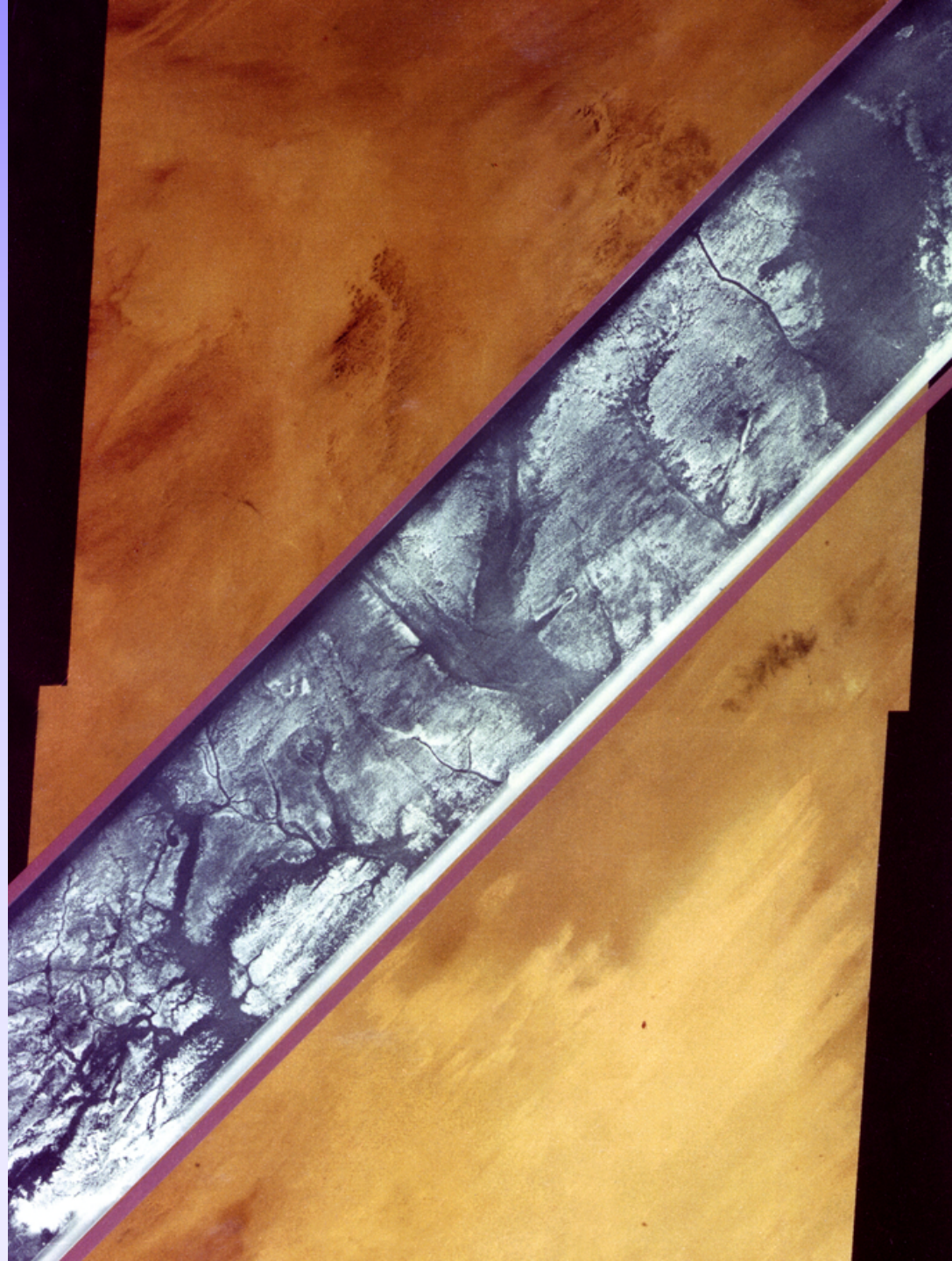
•JPL's Shuttle Imaging Radar-A flew on 2nd flight of Space Shuttle Columbia in 1981

•Images show SIR-A radar over Landsat Multispectral Scanner-Southwestern Egypt

•L band (23 cm) radar images thru 2+ meters of dry sand, shows integrated drainage systems

•Thin sand cover (0-few meters) obscures underlying, older fluvial landscape

•Neolithic artifacts abundant near "radar rivers", evidence for significant human presence



Climate Stability is a Key Factor

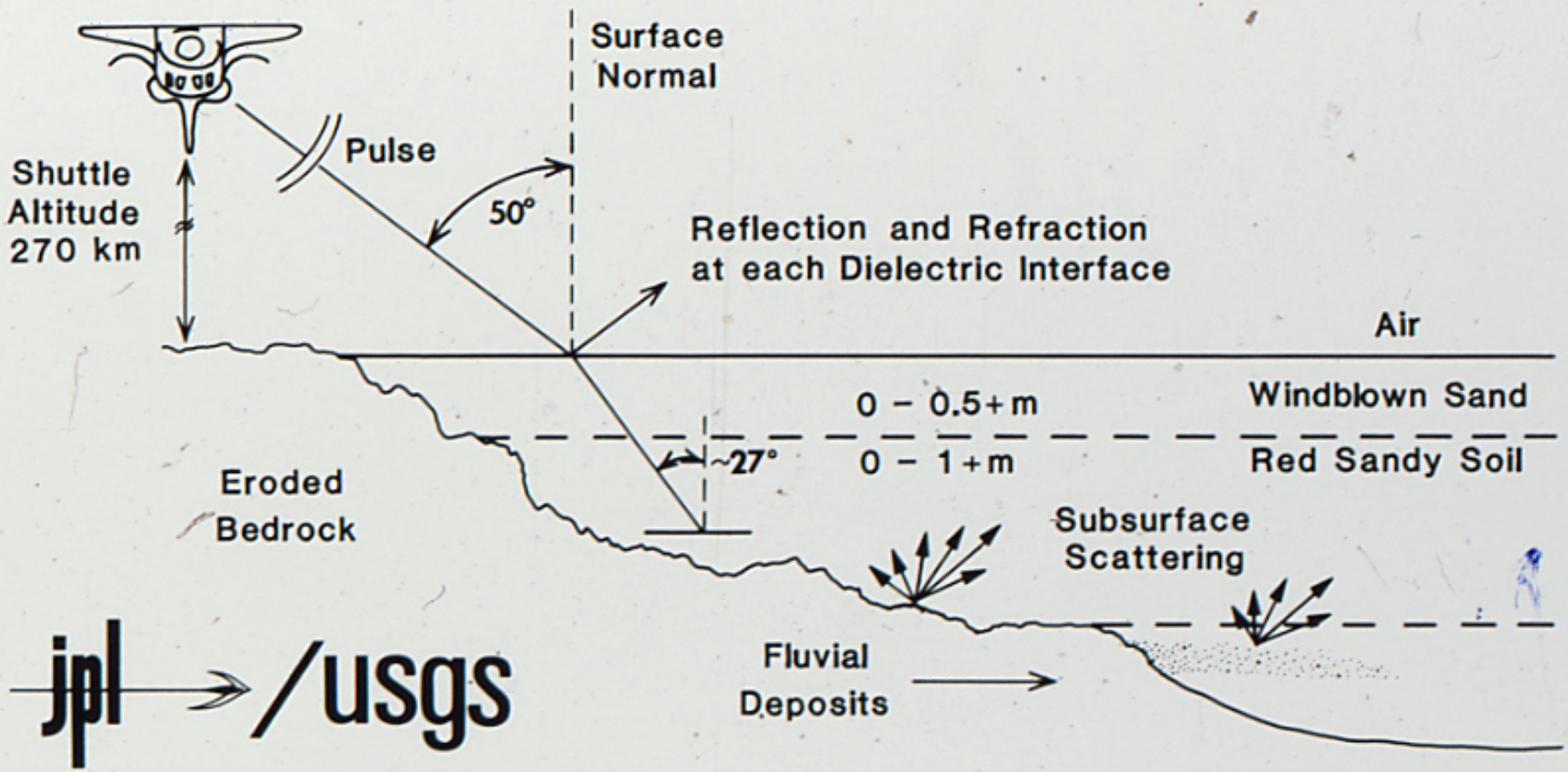
In Development of Agriculture and Complex Societies

Archaeology and paleo climate research aided by space observations can help document this transition, and the history of civilizations.

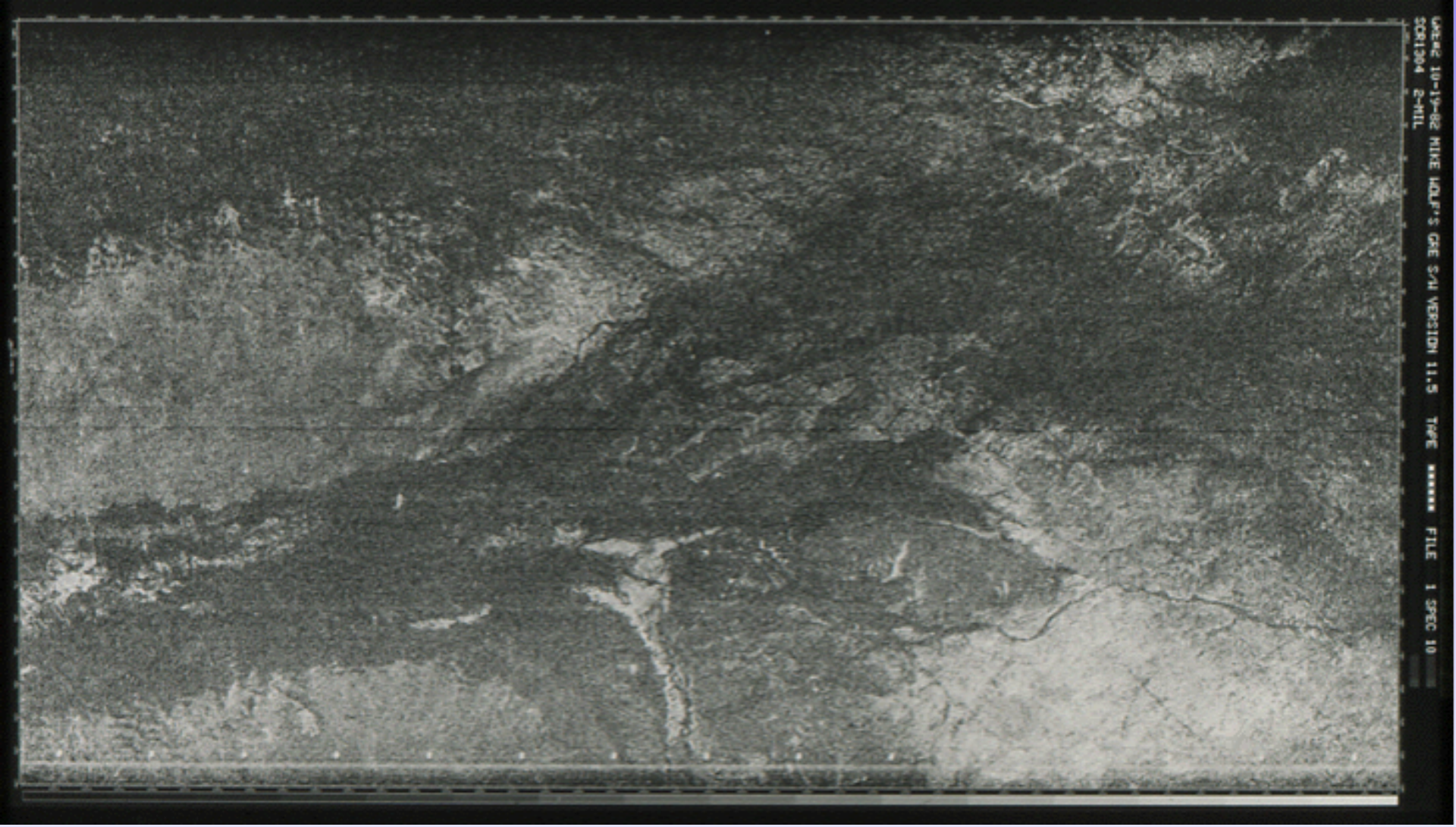
Example: Leaving the Sahara

- Today, the Sahara is one of the driest places on Earth
- Intermittently a grassland until recent drying out about 7,000 years ago

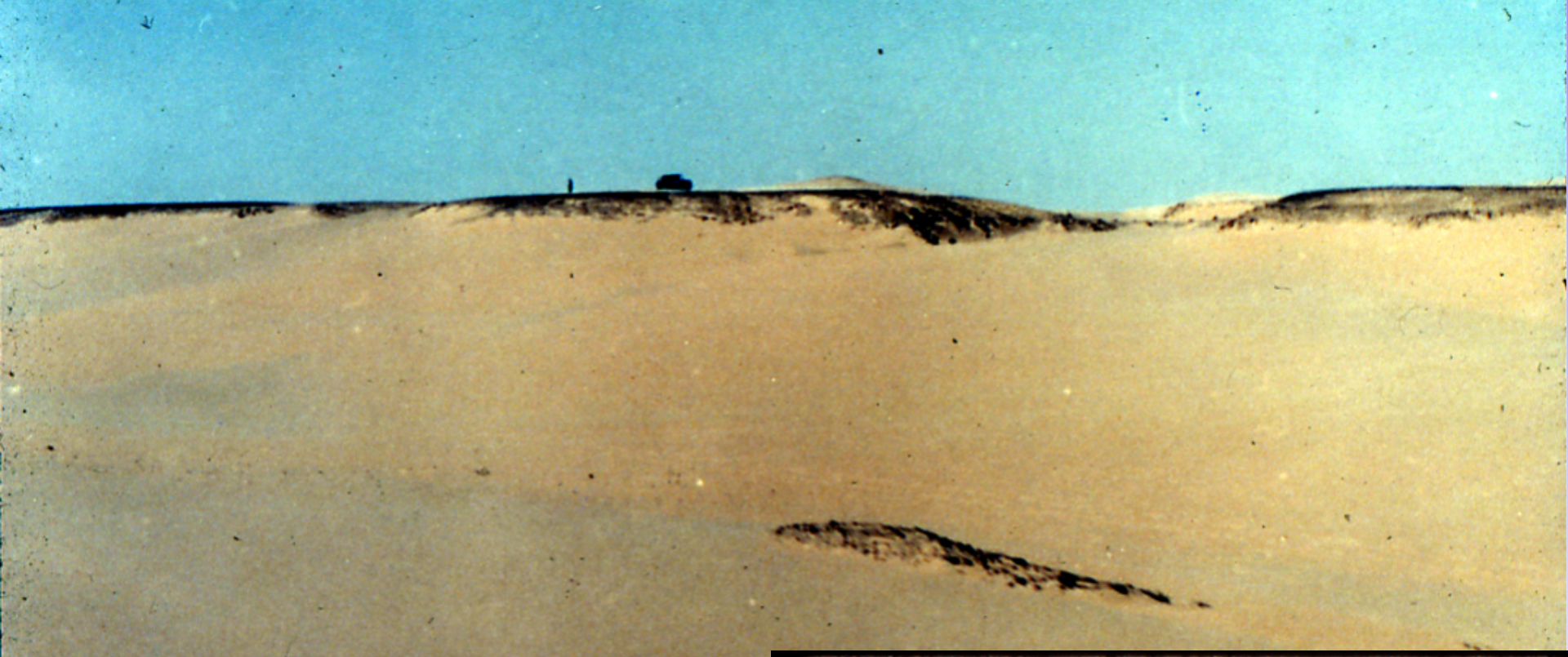
SIR-A Subsurface Imaging - Egyptian Sahara



- Shuttle Imaging Radar-A flies on Space Shuttle Columbia, November 12-14, 1981
- L-band (23 cm) wavelength radar able to see subsurface in this extremely dry environment
- Radar is effectively a "time machine" showing a landscape from an earlier climatic regime



- SIR-A radar image near Egypt Sudan border
- Image coverage is 50 km top to bottom
- Note large and small apparent river channels



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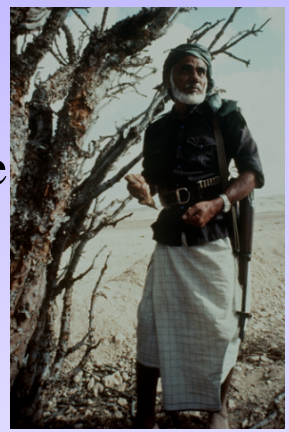
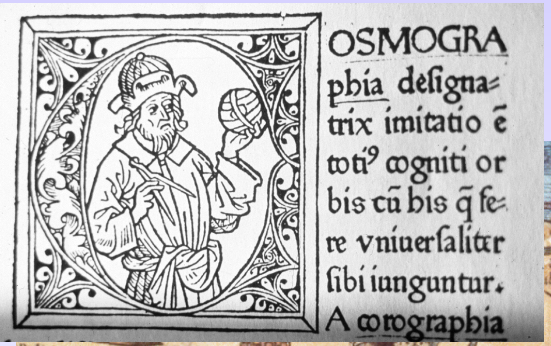
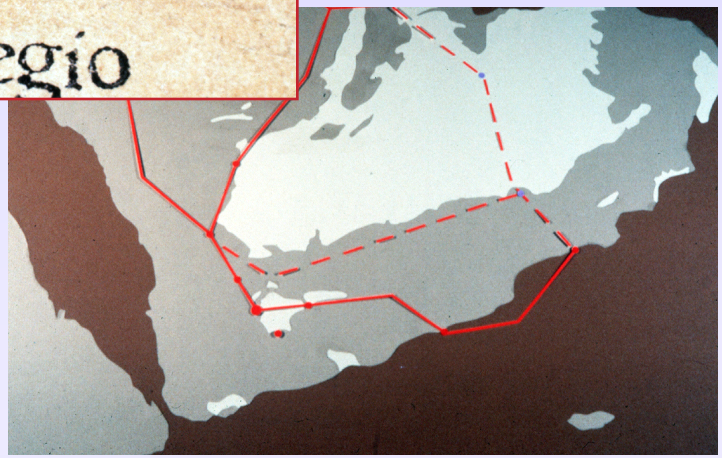
Southern Arabia-Incense Trade Routes

- SIR-A results inspired new thinking-SIR-B (1984) and SIR-C (1994) experiment plans included many desert areas
- Nicholas Clapp contacts JPL
- Legendary accounts of trade routes for Frankincense and Myrrh across the Empty Quarter
- Legends of lost "city" of Ubar, which grew wealthy on Frankincense trade







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Modina	66 ⅓	27 ½ ¼
Hippos mons	66 ½	27 ⅓
Hippos villa	67	26 ⅔
Phoenicum villa	67 ⅓	26 ⅓
Rhaunathi villa	67 ¼	24 ⅔
Chersonesi extrema	67	24 ⅓
Iambia villa	68	24

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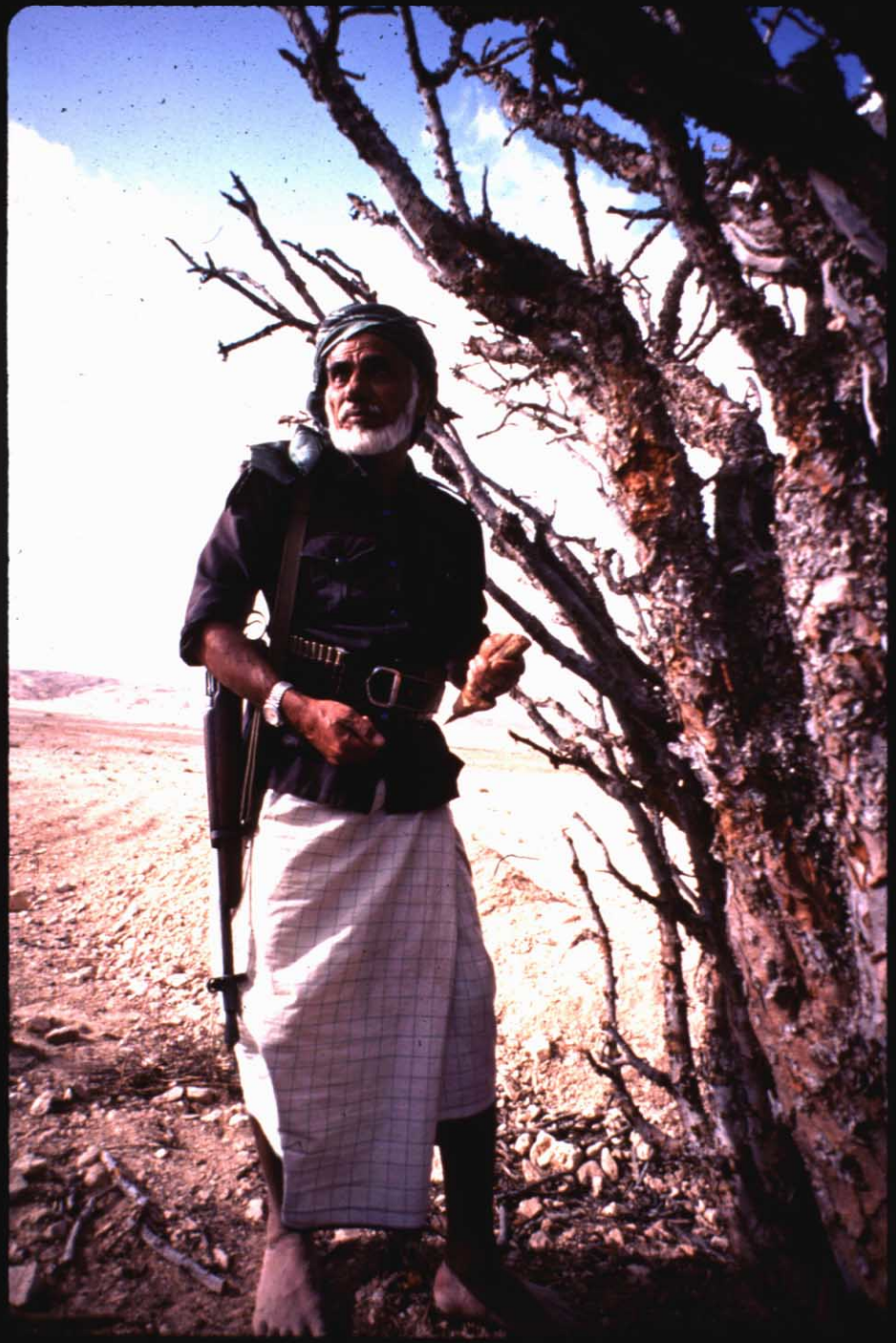
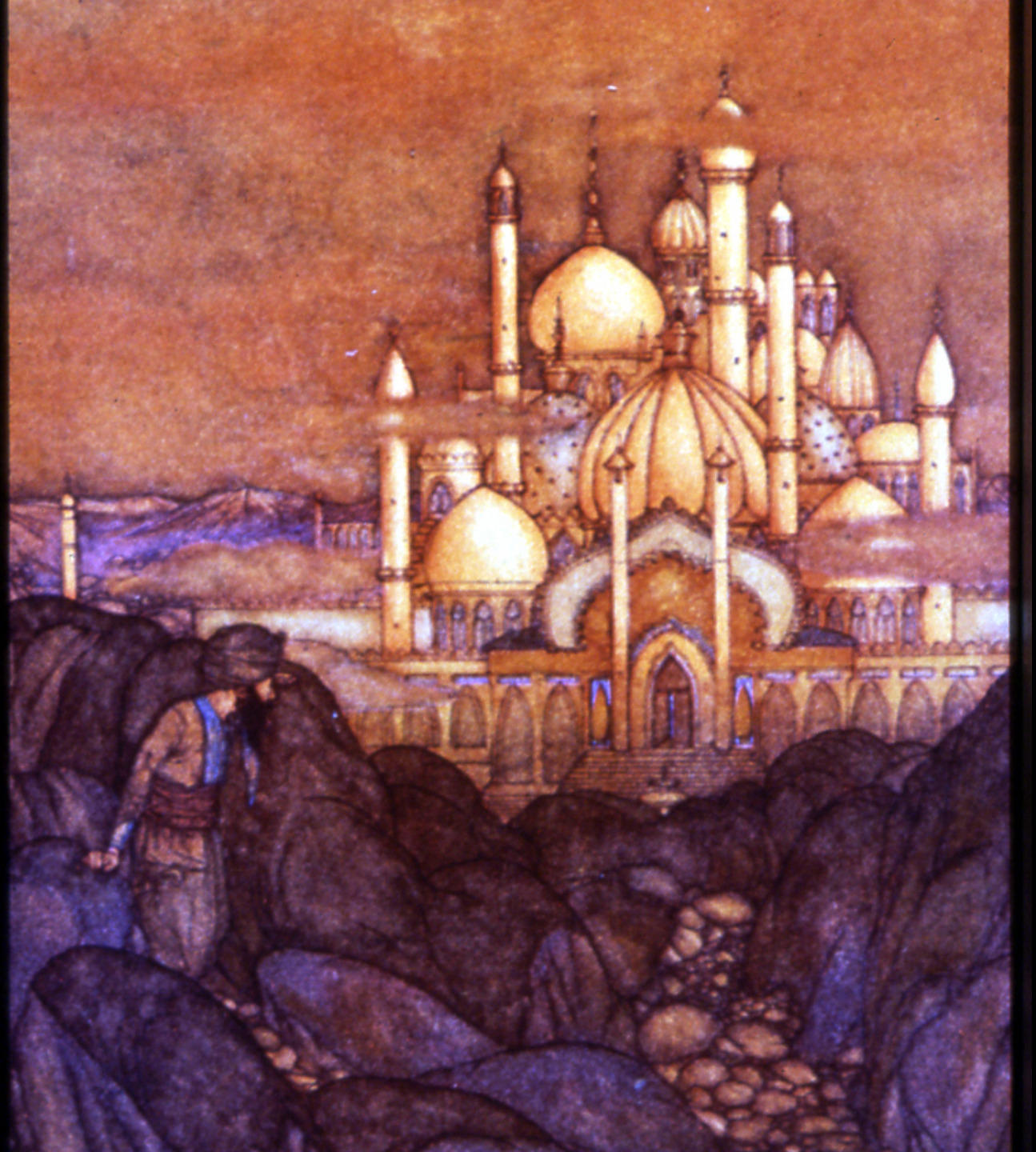
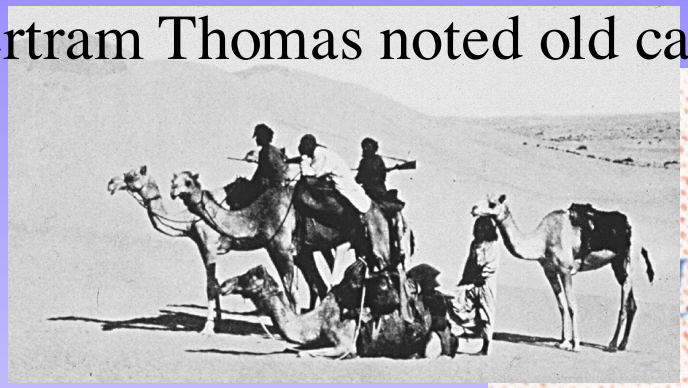
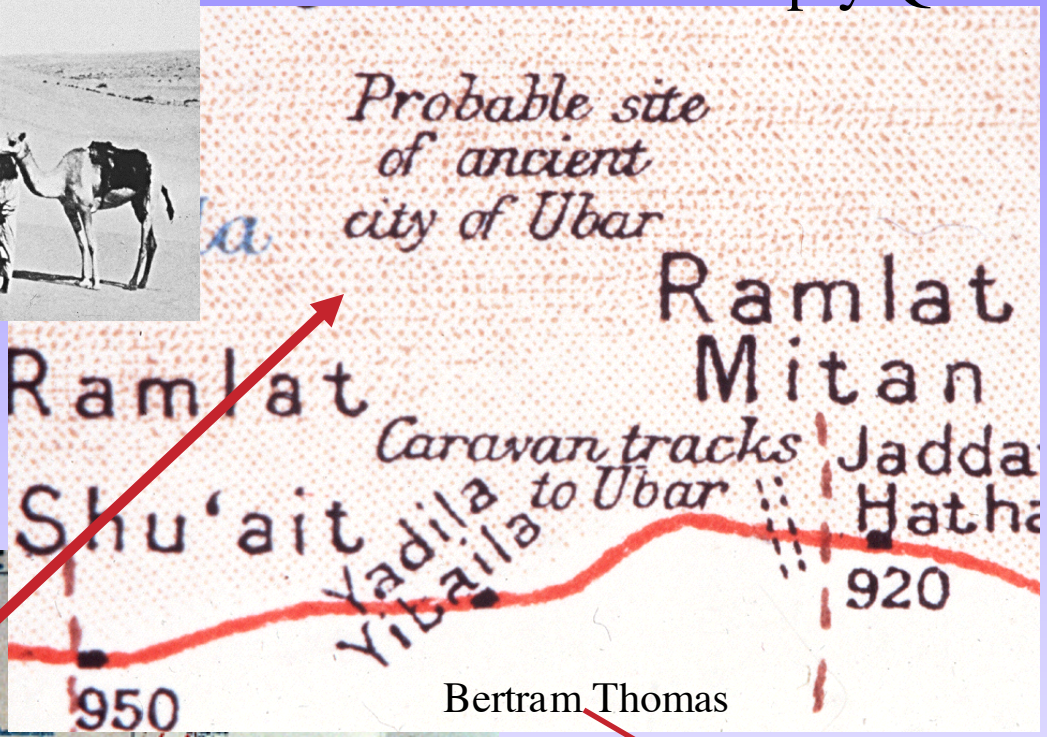




Bertram Thomas noted old caravan tracks in the Empty Quarter-1930's



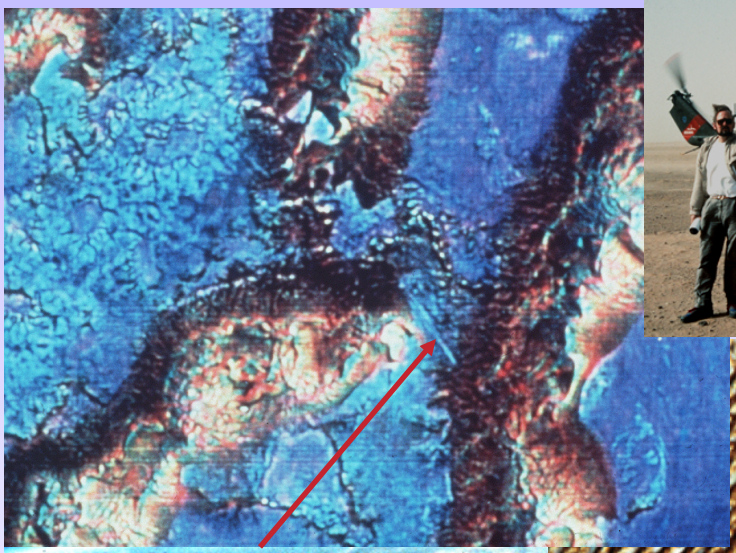


Bertram Thomas

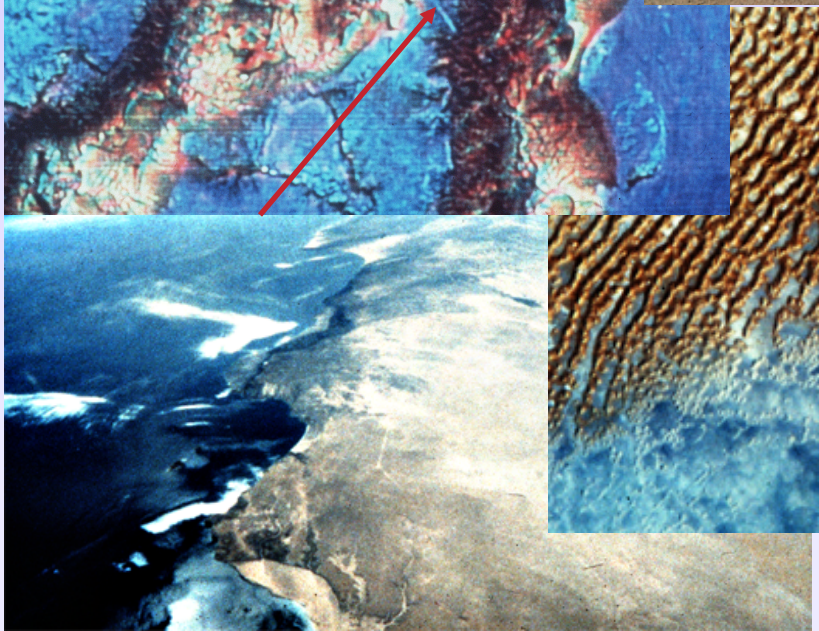
Bertram Thomas, 1932, Arabia Felix: Charles Scribner's Sons, New York, 397 p.

Frankincense Trade Routes-Oman and Yemen

- How to find Thomas' road? Possible sites??
- Landsat Thematic Mapper (TM) and SPOT images used, search centered on Betram Thomas' reported location
- Expression of desert trails clear on carefully enhanced satellite images



Neolithic!



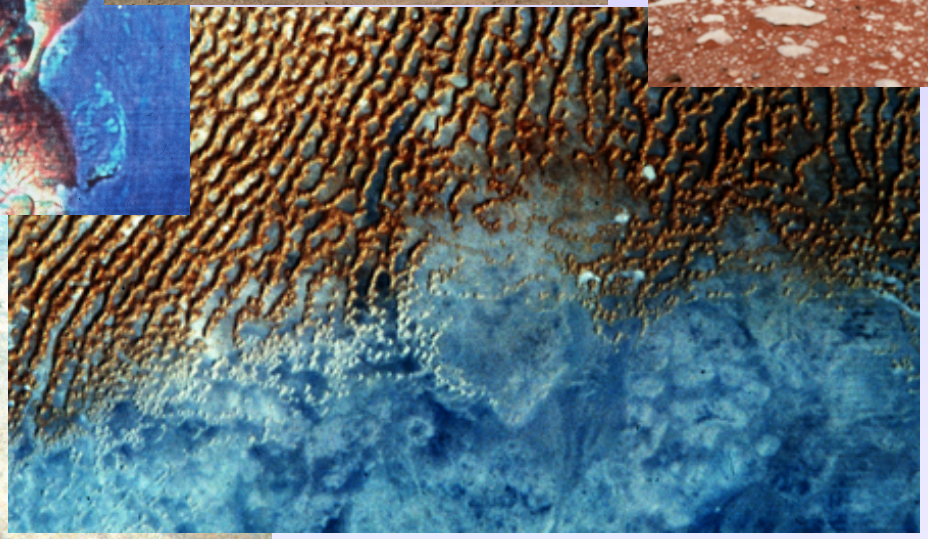
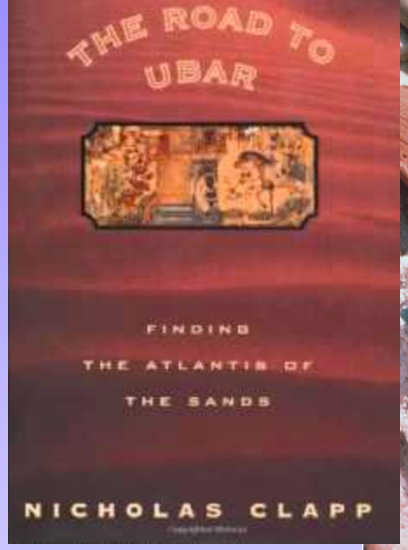


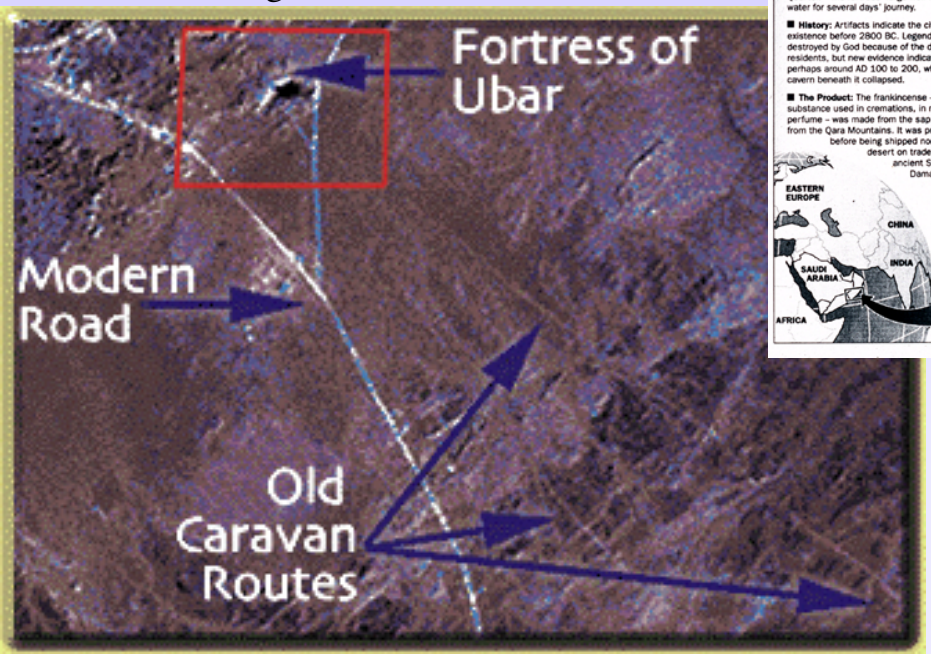
Image processing
by Bob Crippen

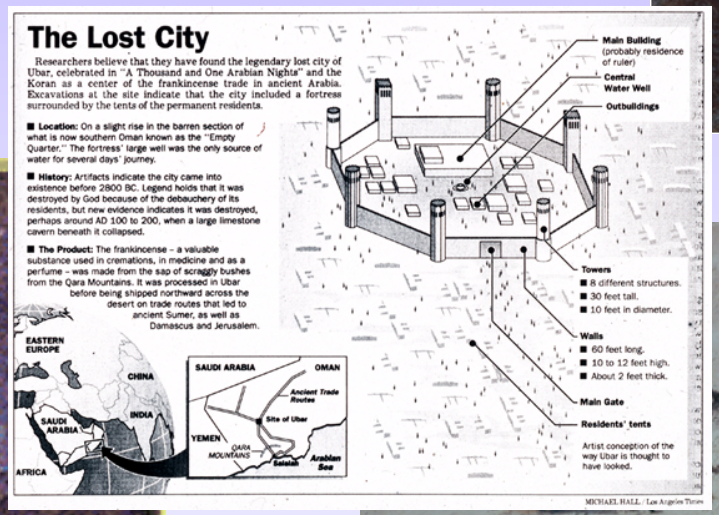
- Bronze Age site at Shisr may have provided some elements of "Ubar" story
- Only major site in the region, roads go to Shisr
- In the land of the "Ibarotie" of Ptolemy's map
- Follow-on work on trade routes in Yemen
- "Land of Frankincense" now nominated as UNESCO World Heritage Site
- http://whc.unesco.org/en/list/1010/

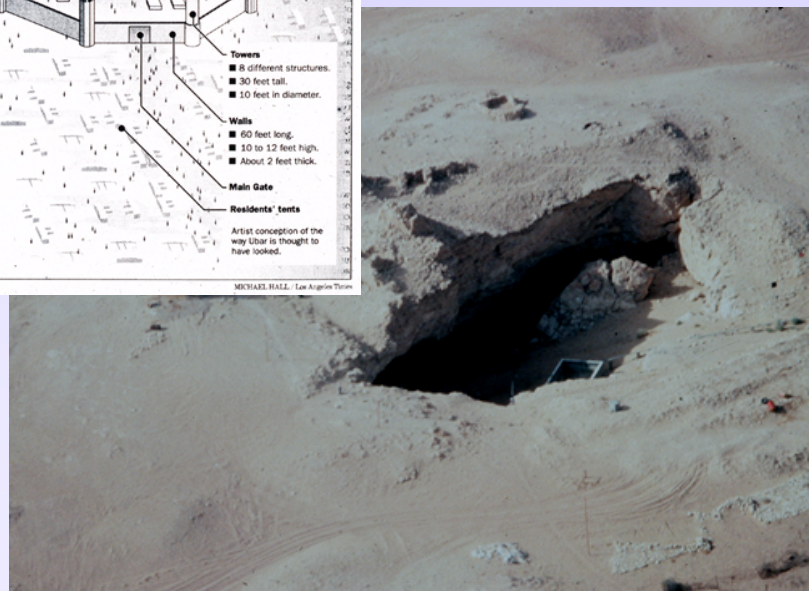


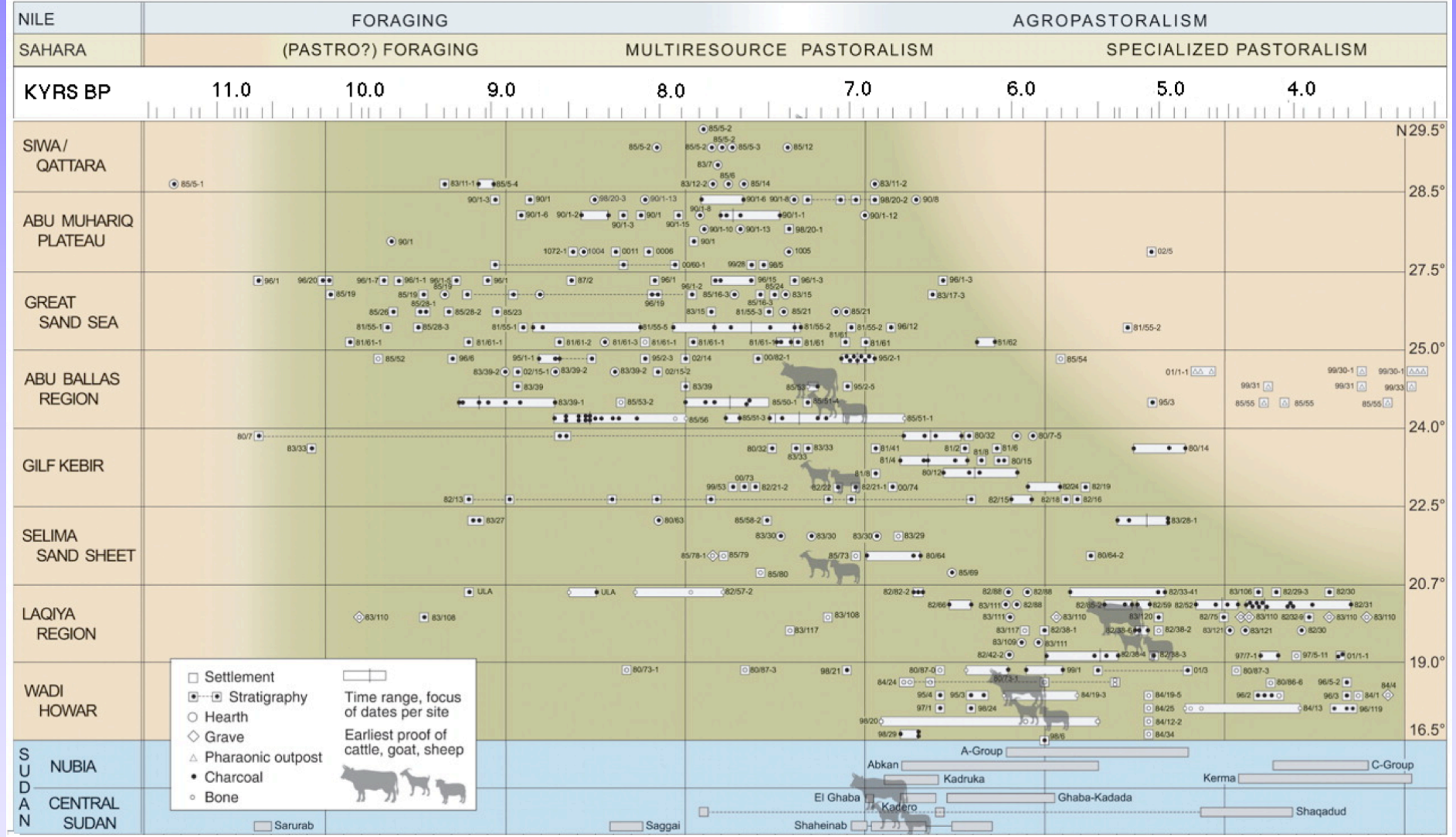
Book-published 1998

Landsat TM image









Human Occupation of the Sahara from Kuper & Kroepelin, Science, 2006.

Data from over 150 archaeological sites, maximum occupation of the Sahara at ~7.9K yrs

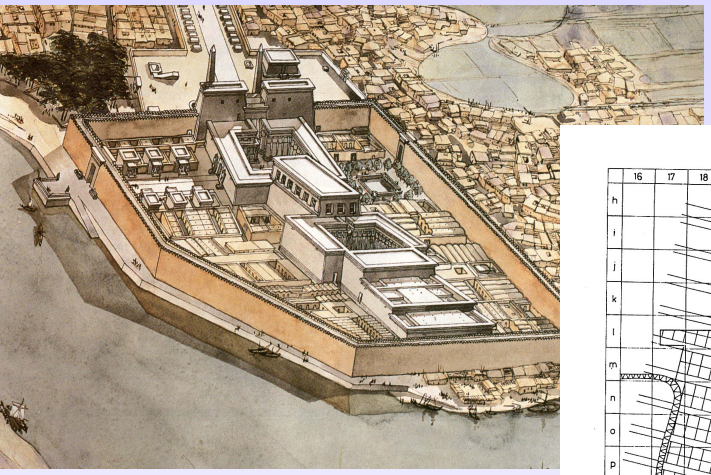
Where did people go when the Sahara dried out? They retreated south, and towards the Nile

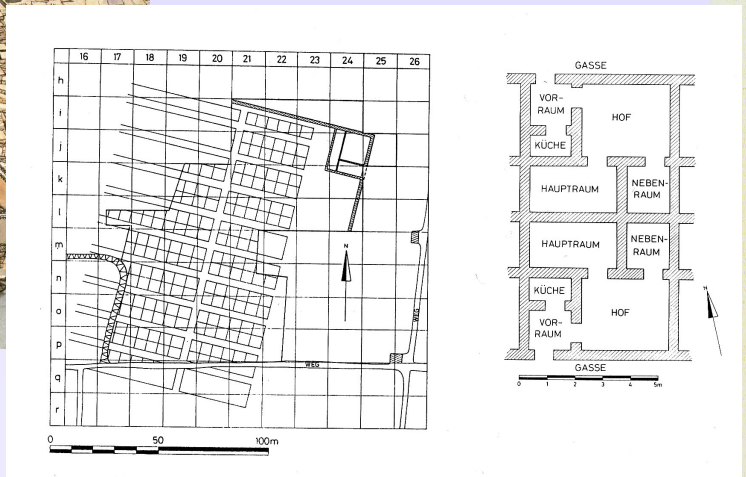
The End of Egypt's Pyramid Age from Space

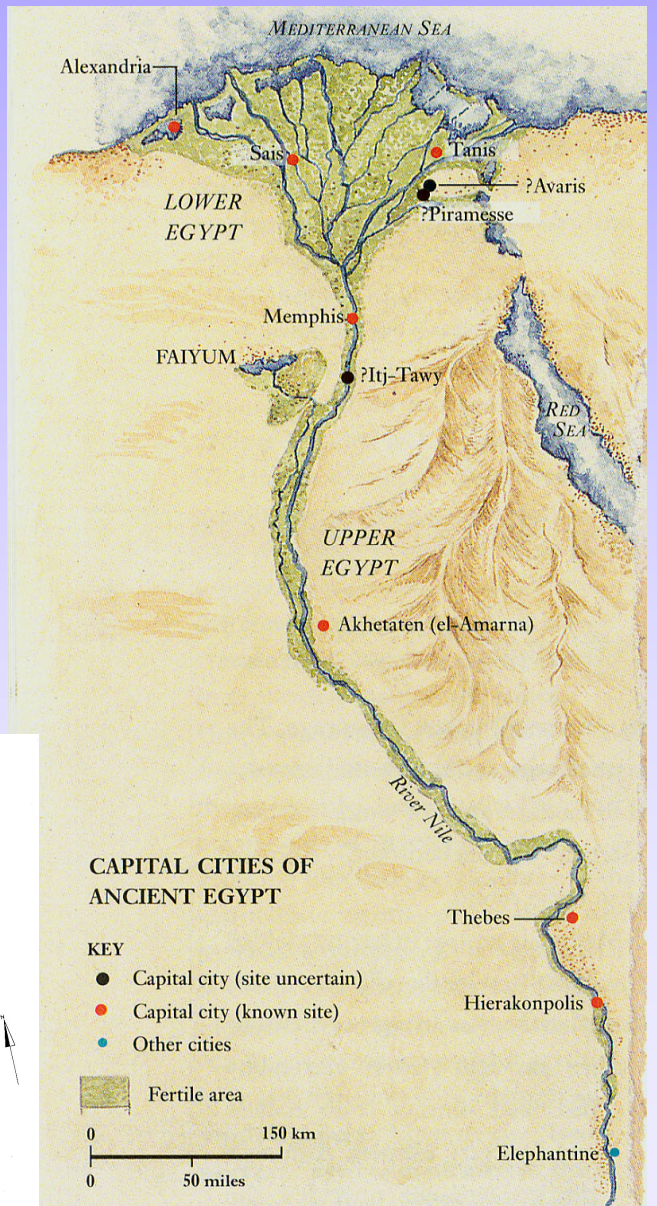
Prof Sarah Parcak, UAB

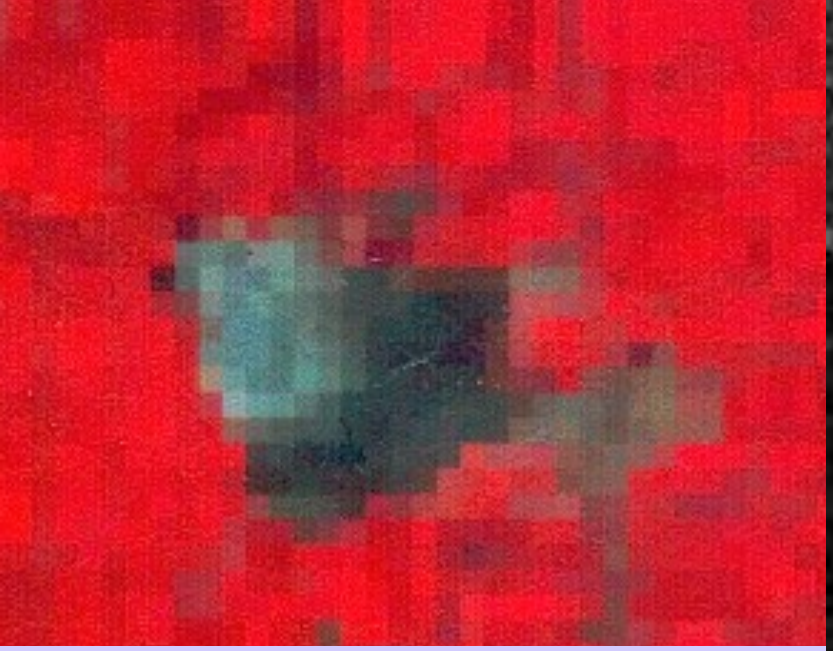
Settlement Pattern Studies in Egyptology

- Limited time, sites being over run by development
- Where are all the sites?
- How many towns/villages/cities?
- What time periods?
- Role of remote sensing-help find and document sites provide regional context

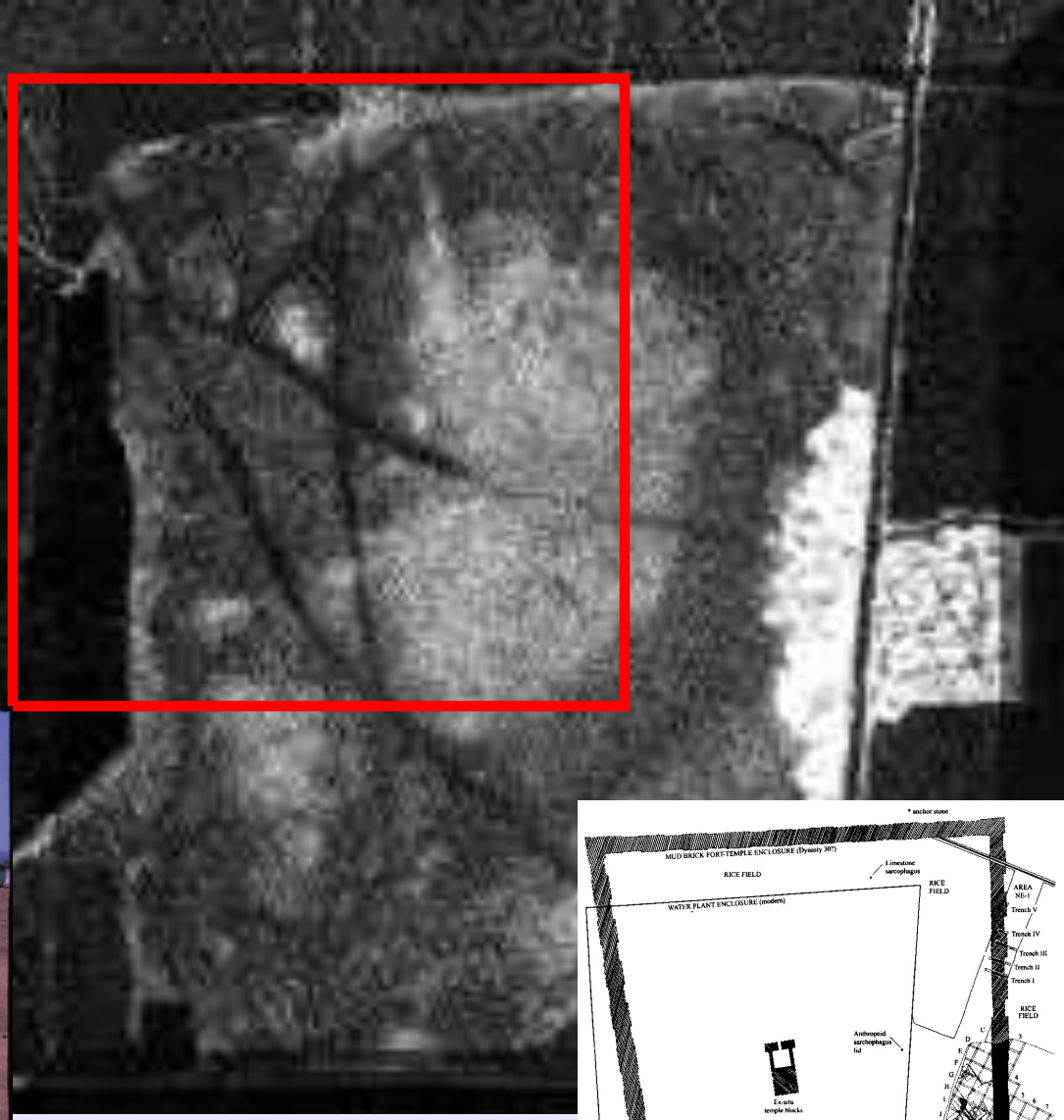








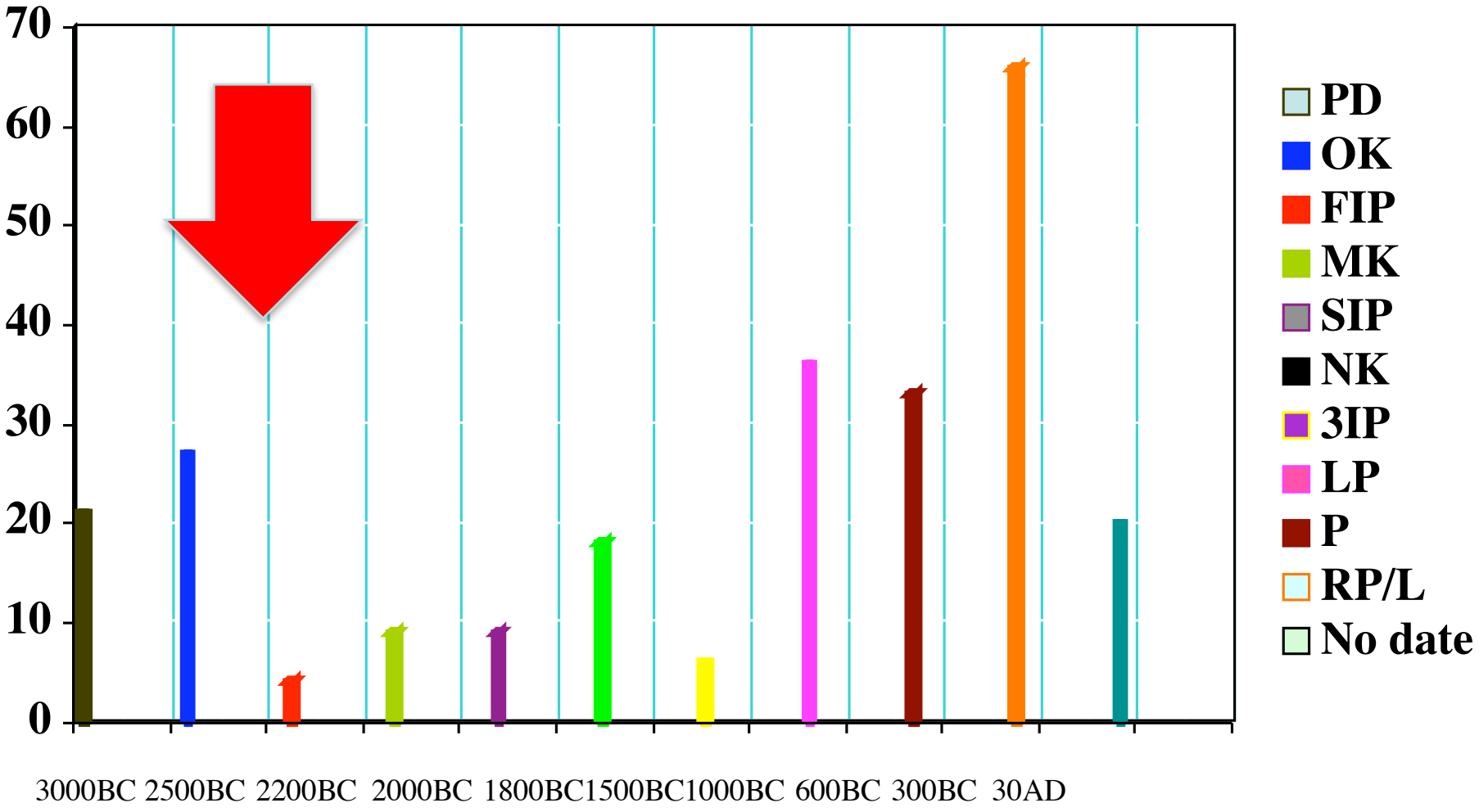
Landsat image of Tell Tebilla



•Corona spy satellite *PHOTOGRAPHIC* image of Tell Tebilla

•Remote sensing data tells archaeologists where to look

Site dates over time



Egypt: Why and how did the Old Kingdom collapse?

• Multiple factors with varying significance lie behind the Old Kingdom's decline:

Late Old Kingdom, Dyn. 6+:
Last straw? vs. Cumulative?

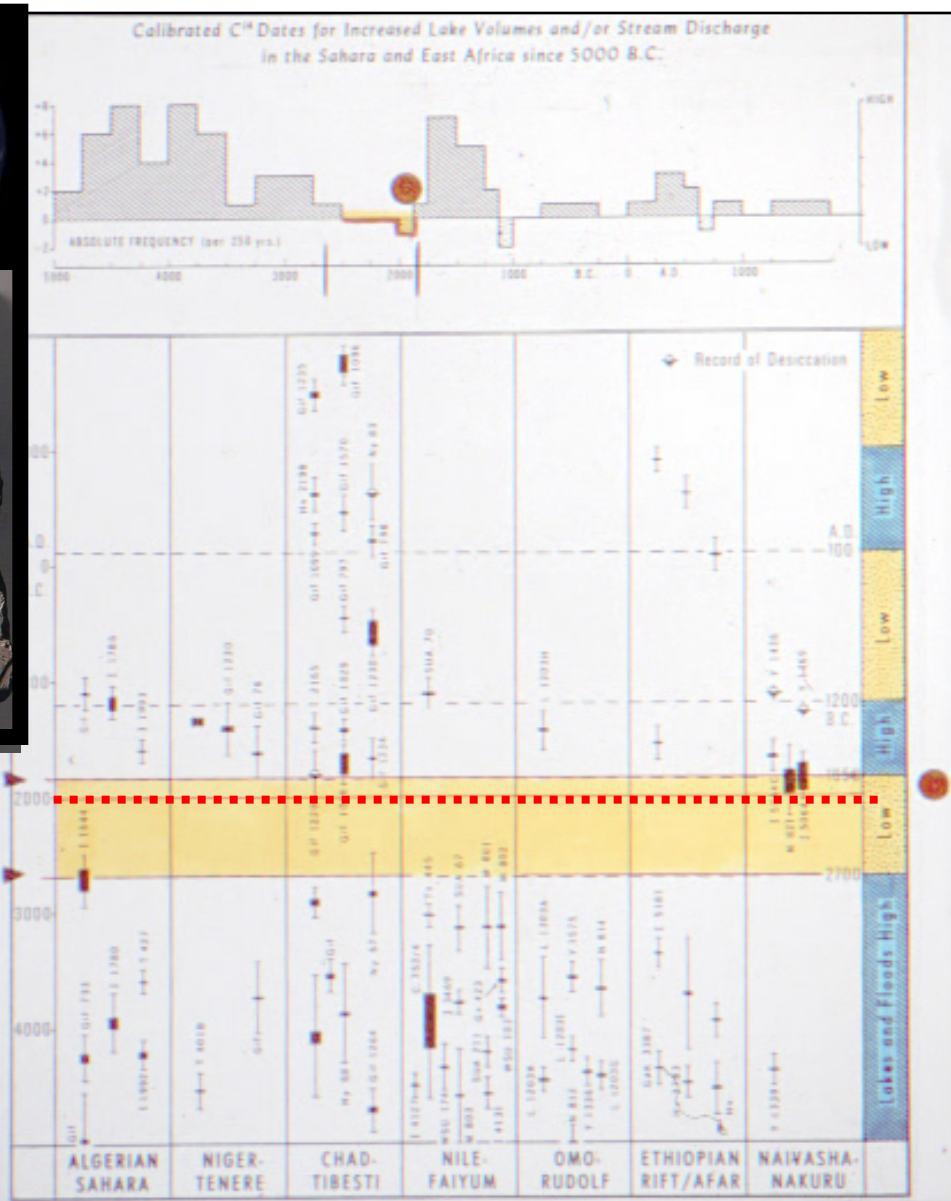
•**Great droughts**
ended Neolithic Wet-Phase,
1 meter drop in Nile height
→ **reduced crop & income**.

• **Drop in king's power**
through failure to obtain
adequate Nile flood levels

The king, as a living God,
has failed….regime change…

?changes in ocean circulation
>weak monsoons contribute to near contemporaneous "decline/collapse" elsewhere.
Courtesy: Prof. Sarah Parcak UAB

2200 BC climatic & socio-cultural changes across globe



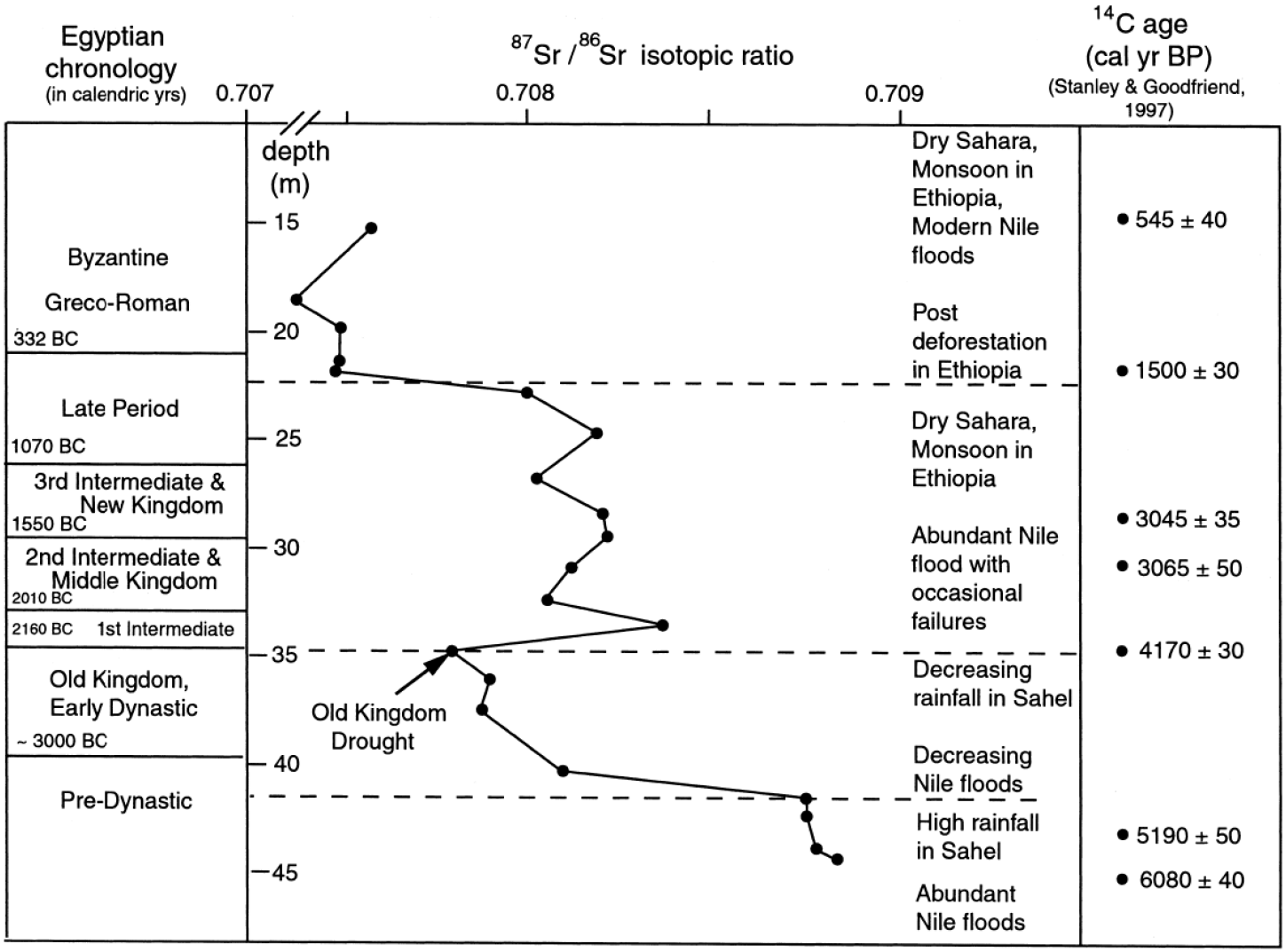


Figure 2. Depth profile of $^{87}Sr/^{86}Sr$ from core S-21 in the Nile delta (at coast, east of Suez Canal; see Figure 1D), together with interpretation of changes in paleoclimate in the catchment and the state of the Nile flood as given in Krom et al. (2002). The Egyptian chronology in calendric years, from Kitchen (1991), is given in the left-hand column. The ^{14}C calibrated age of the core, calculated by linear regression, together with the individual points from which the time-scale was derived (Stanley and Goodfriend 1997), corrected for a 400 year initial age, are presented in the right-hand column. For details of sample treatment and geochemical analysis of the $^{87}Sr/^{86}Sr$ isotopic ratio see Krom et al. (2002).

Stanley, et al, 2003, Nile flow failure at the end of the Old Kingdom, Egypt: Strontium isotopic and petrologic evidence: Geoarchaeology: V 18, p. 395-402

SUMMARY of Old Kingdom's "collapse" (actually = decline)

• **Multiple factors with varying significance lie behind the Old Kingdom's collapse:**

Late Old Kingdom: SUMMARY OF FACTORS.

Growing impoverishment of royal court:

- Tax exemptions; furnishing & maintaining cults;

Political decentralization: placating the nobility.

- Wealth & power to provinces
- Non-royalty assuming high offices (Vizier)
- Governors residing in provinces

Increasing aridity ends Wet-Phase

- Reduced crops → famines → no surplus → regionalism (why re-distribute provincial grain?)

Drop in king's prestige as "gods' representative":

- Doesn't fulfill duty maintaining prosperity etc.

Increasing attacks from marginal regions: Bedu.

- Expeditions abroad; incursions (?)

Instability over succession at end of Dyn. 6:

- Pepy II reigned 94 years; succeeded by Queen
- Assassination of last ruler & turmoil
- Dyns.7-8: many rulers; marriage alliances

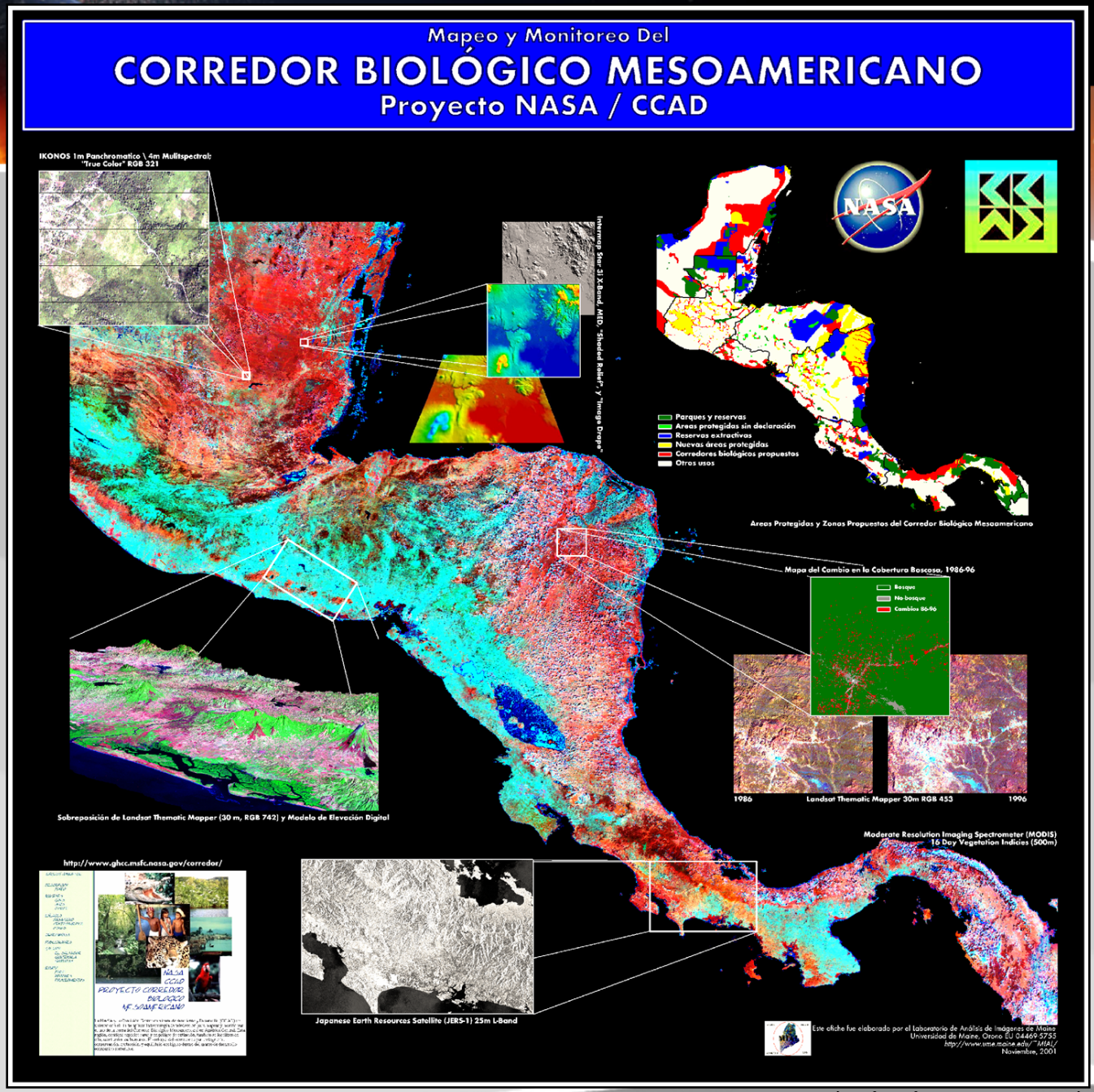
~2200 BC global climatic event → many effects

The 4.2K yr event-Possible change in circulation of Atlantic currents may have induced weak monsoons contributing to "decline"/"collapse" within Egypt, Syria-Palestine, Turkey, Mesopotamia, and the New World as well.

Akkadian empire decline particularly interesting as north was supported by rain enabled agriculture, south by irrigation from Tigris and Euphrates.

Weiss, Harvey and Raymond S. Bradley, 2001, What drives societal collapse? Science, 291: 609-610.


Utilizing the Unique
View from Space
NASA
SERVIR
Regional Visualization and Monitoring System
An Environmental
Monitoring and Decision
Support System for
Mesoamerica
Courtesy: Dan Irwin and Tom Sever
http://www.servir.net/



www.nasa.gov/mission_pages/servir/

Classic Maya Period ~300-900

Archaeologists have turned to various types of satellite and airborne data sets to supplement their investigations.

Ancient Maya Cities

Maya Decline/Collapse: A Demographic Disaster

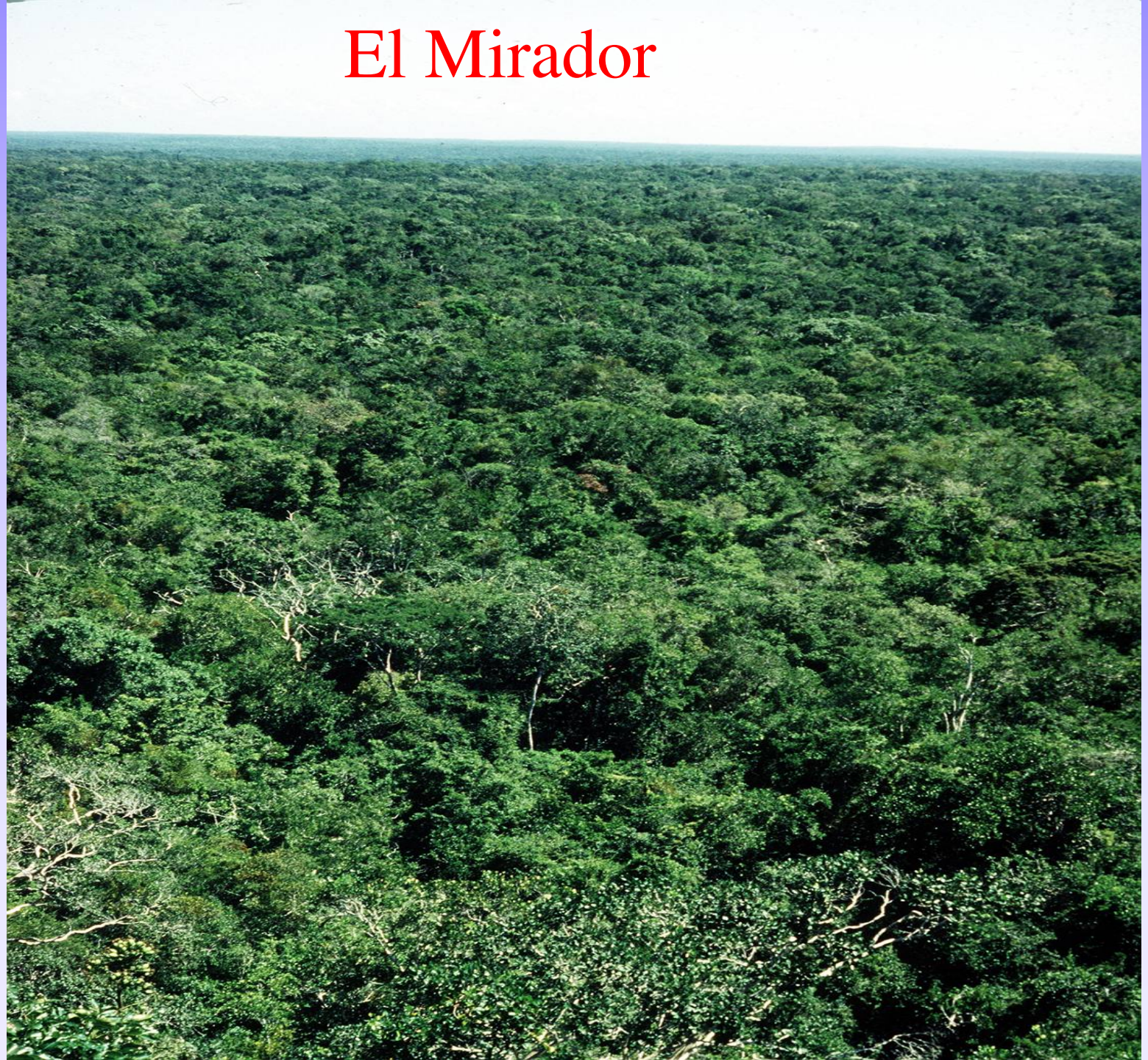
Dozens of explanations for the Maya Collapse including:

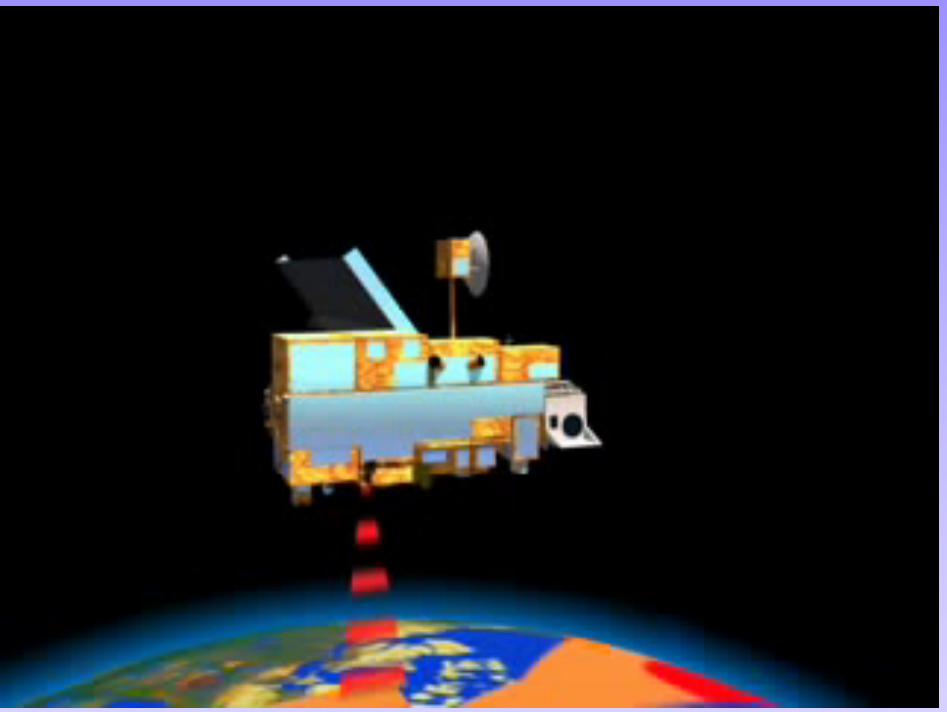
- Hurricanes
- Over population
- Disease
- Deforestation/Soil Erosion
- Peasant Revolt
- Warfare
- Drought and Climate Change

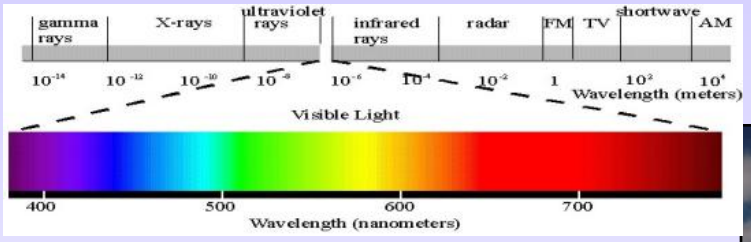
El Mirador

http://news.nationalgeographic.com/news/2006/12/photogalleries/apocalypto/

El Mirador





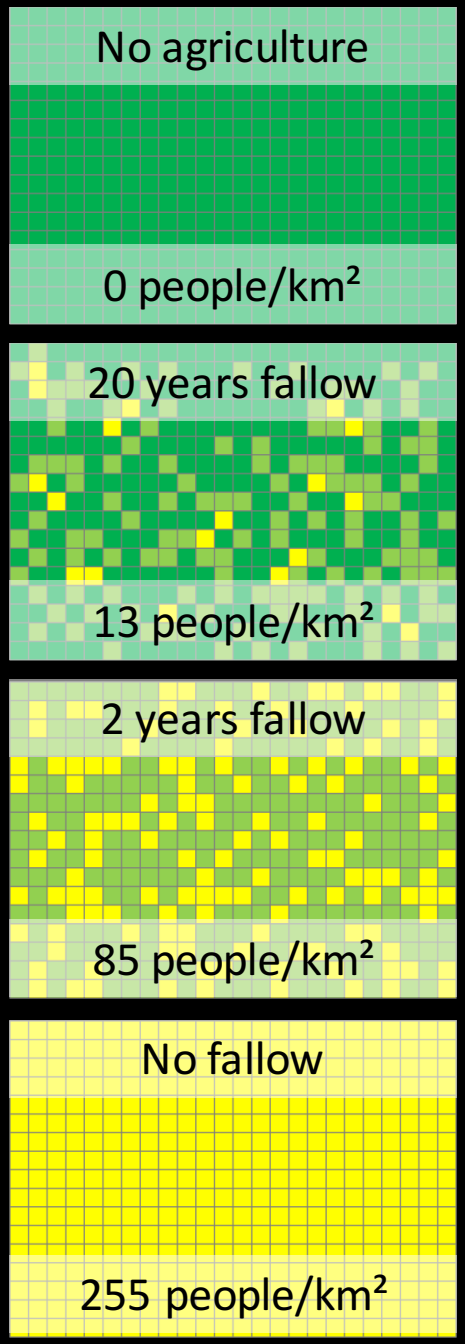


Satellite and other space based data essential for mapping current conditions and changes in the region

The Maya Agricultural Landscape

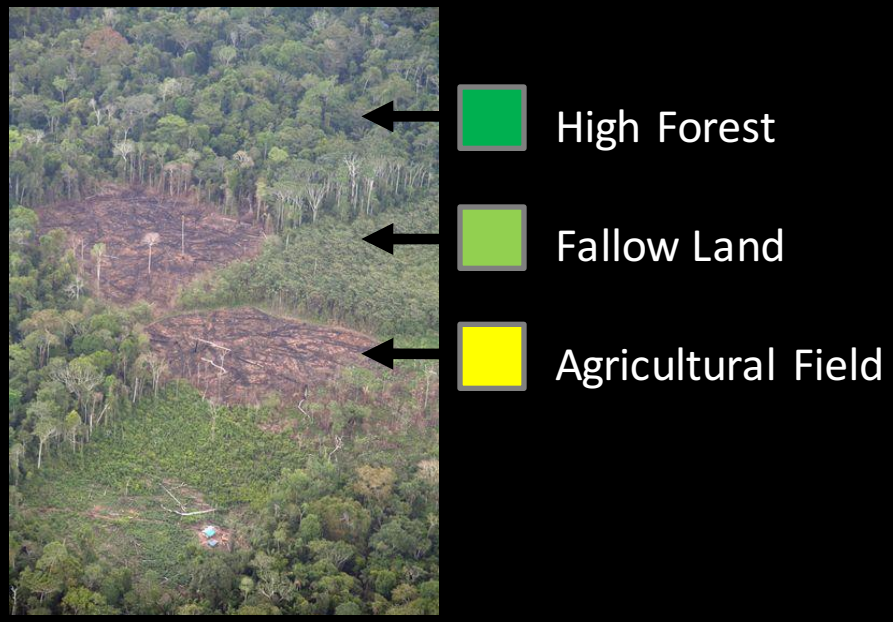
slash-and-burn farming

decrease in fallow / increase in population

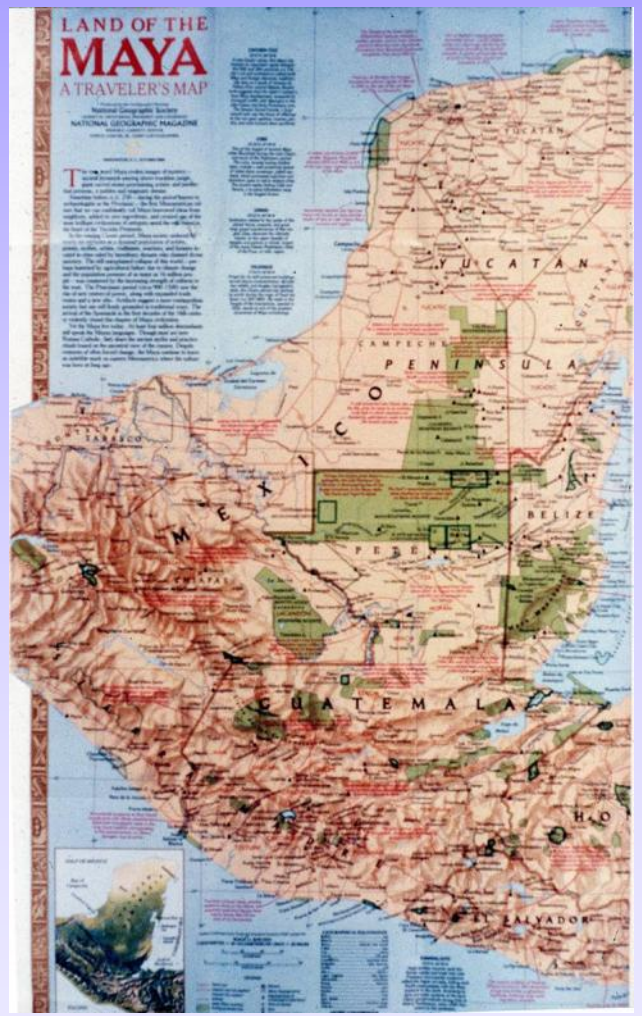


With adequate fallow (rest periods) the landscape is a patchwork of high forest, short secondary forest, and active agricultural fields.

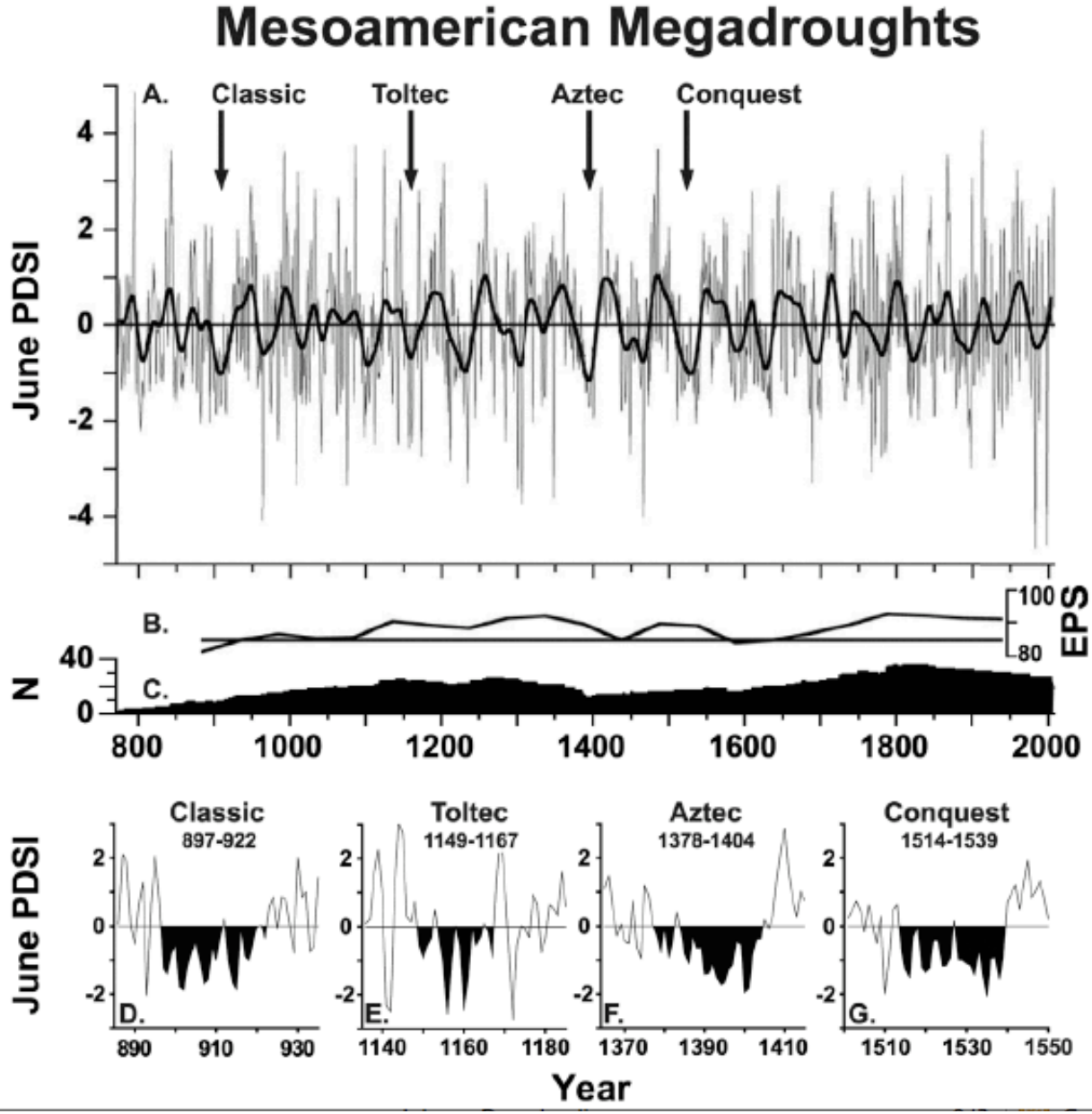
Fallow periods can be shortened, allowing populations to grow in the short term, however the long term agricultural productivity and **sustainability** of the system are threatened.



For hundreds of years the Maya depended on the predictable rain cycle.



With all reservoirs full, they had an 18-month supply of water.


Mesoamerican Megadroughts
A.
Classic
Toltec
Aztec
Conquest
June PDSI
4
2
0
-2
-4
B.
100
80
EPS
N
40
0
C.
800
1000
1200
1400
1600
1800
2000
Classic
897-922
Toltec
1149-1167
Aztec
1378-1404
Conquest
1514-1539
June PDSI
D.
E.
F.
G.
890
910
930
1140
1160
1180
1370
1390
1410
1510
1530
1550
Year

AIRSAR http://airsar.jpl.nasa.gov/

- AIRSAR-JPL's experimental Airborne Synthetic Aperture Radar System
- AIRSAR now decommissioned
- Flew on NASA's DC-8 flying laboratory based at Dryden, CA
- POLSAR-3 wavelengths and full Polarization diversity helps characterize targets
  - P, L, and C band at HH, HV, VH, VV polarizations
  - 3 modes 20, 40, and 80 MHz bandwidth.
    - Resolution increases with bandwidth while swath decreases
    - 80MHz L band resolution is 1.7m, 40 MHz is 3.3m, 20 MHz is 6.7m
    - Swath width is 5km@80MHz, 10Km@40MHz and 15Km@20MHz
    - Image calibration 3dB absolute, 0.2dB cross pol, 1.5dB between bands
- TOPSAR-Generates Hi Res DEMs at two wavelengths
  - Cross track interferometry
  - L and C band Digital Elevation Models (DEMs)
  - DEM postings at 5m (40 MHz), 1-3 m height accuracy

Current Antenna Configuration

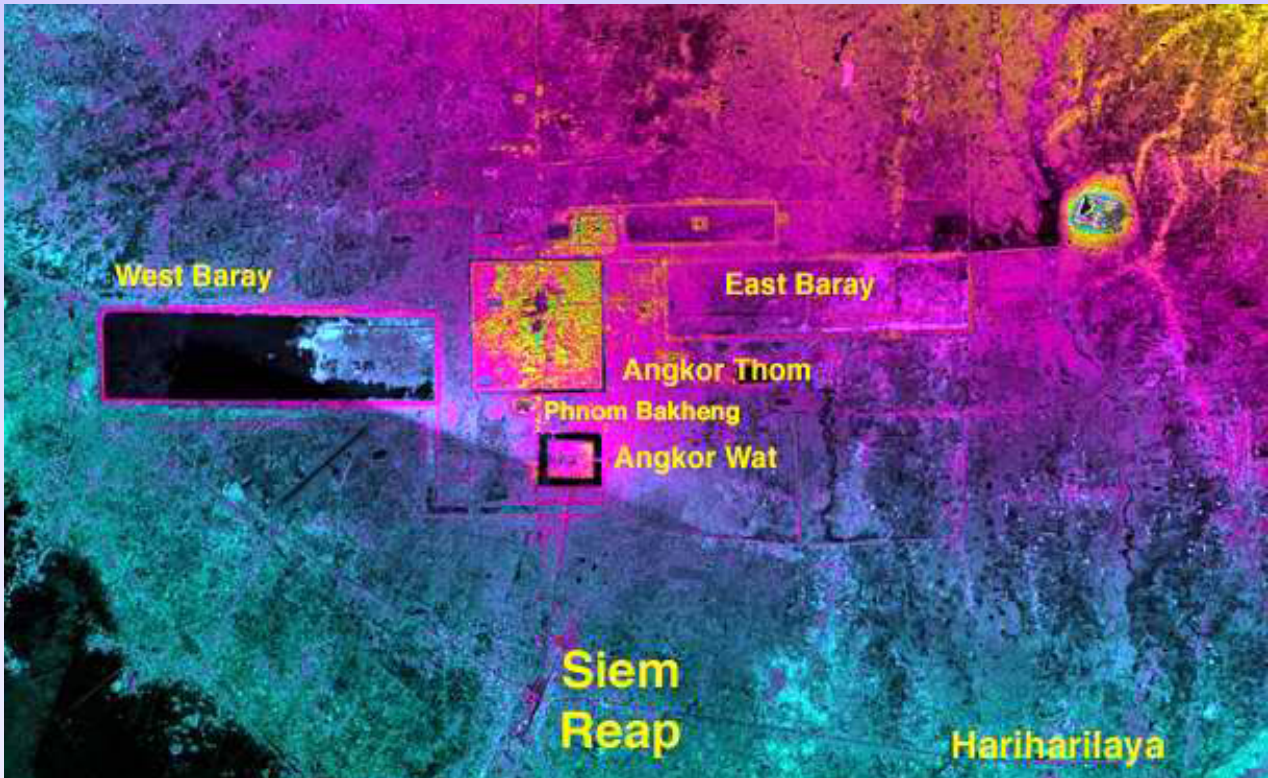
AIRSAR Instrument

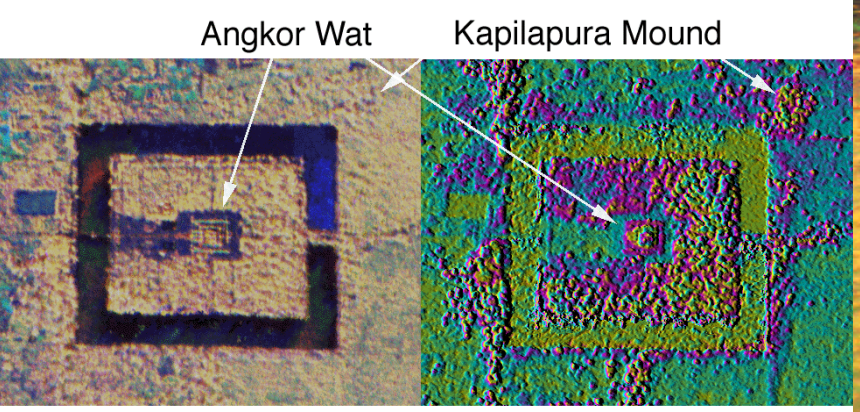
Angkor Wat Region Cambodia AIRSAR Data from PACRIM 2000

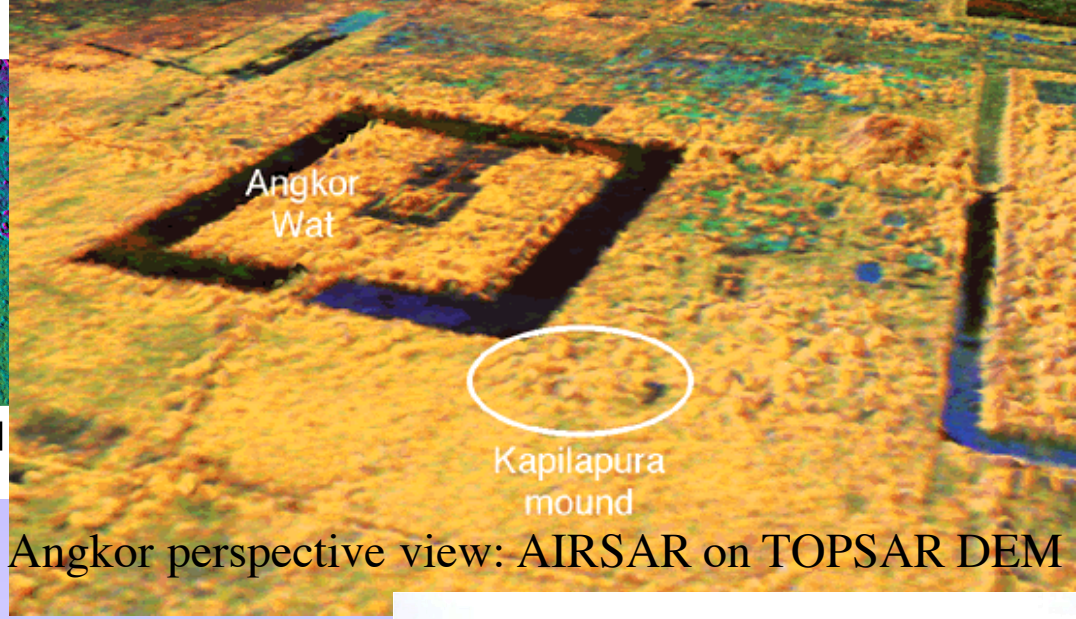
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

- Angkor Wat-major religious/urban center and water system, ~9th-15th centuries
- Angkor region imaged by SIR-C and AIRSAR
- AIRSAR campaign also collected high resolution TOPSAR DEMs
- Social disorder and drought>abandoned by 1431
- Collaborative efforts led by Roland Fletcher, Damien Evans U. Sydney, Elizabeth Moore, U. College London

Angkor Wat Temple: Andrew Lih





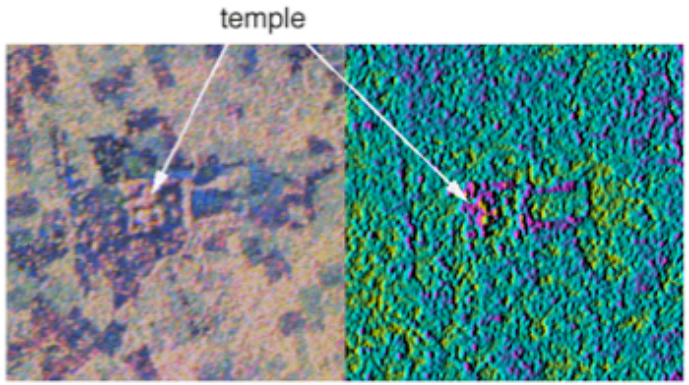


Angkor perspective view: AIRSAR on TOPSAR DEM

Angkor lessons

- Archaeological structures sometimes show both in radar images and DEM
- Archeological structures often show only in DEM
- DEM provides water management insight
- Latest work incorporates very high resolution LiDAR

Sman Teng Temple



Archaeologists commute to work

Angkor Wat

•U Sydney's Greater Angkor Project (GAP), aided by AIRSAR, LiDAR and other remote sensing data have documented ~1000 additional temple sites, thousands of occupation mounds, ponds, canals, etc stretching across more than 1500 km^2

•Angkor was an extensive urban complex with an increasingly elaborate water management system. Population perhaps 1M at peak

•Angkor suffered many problems, current research focus by GAP indicates monsoons may have become erratic starting about 1300 (Little Ice Age); invasions and other disorder occur, barays silt up, rice yields drop

•Angkor declines after 1300's, infrastructure deterioration and environmental degradation contribute, abandoned by 1431

Fig. 1. Oblique aerial views of remnant Angkorian urban features. (*Upper Left*) Occupation mounds and ponds. (*Upper Right*) Canals and embankments. (*Lower Left*) Multifunction roadway/canals. (*Lower Right*) Classic "village temple" configuration.

Evans, et al, 2007, A comprehensive archaeological map of the world's largest preindustrial settlement complex at Angkor, Cambodia**:** PNAS, v. 104

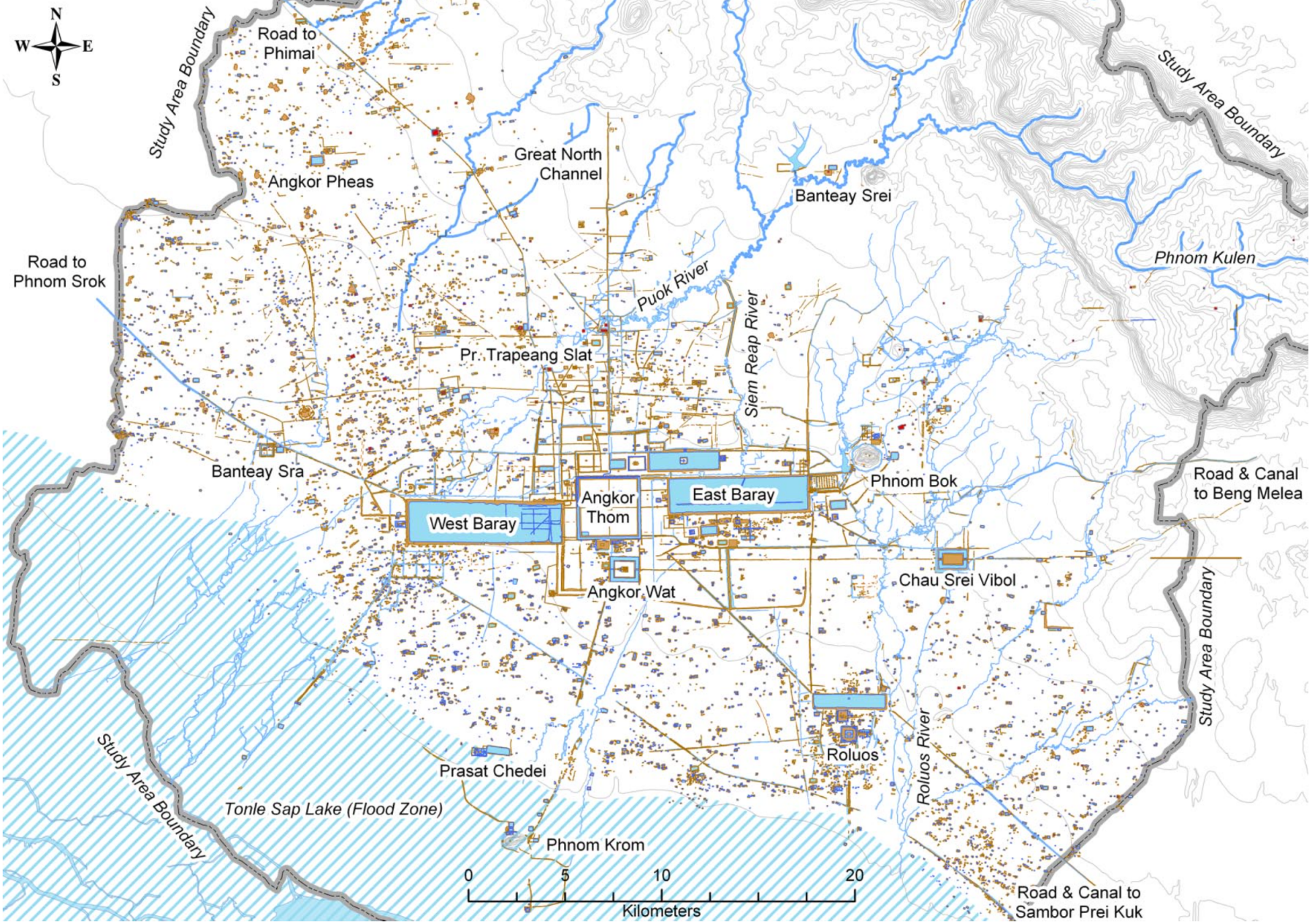


Fig. 2. A new archaeological map of Greater Angkor.

Evans, et al, 2007, A comprehensive archaeological map of the world's largest preindustrial settlement complex at Angkor, Cambodia**:** PNAS, v. 104

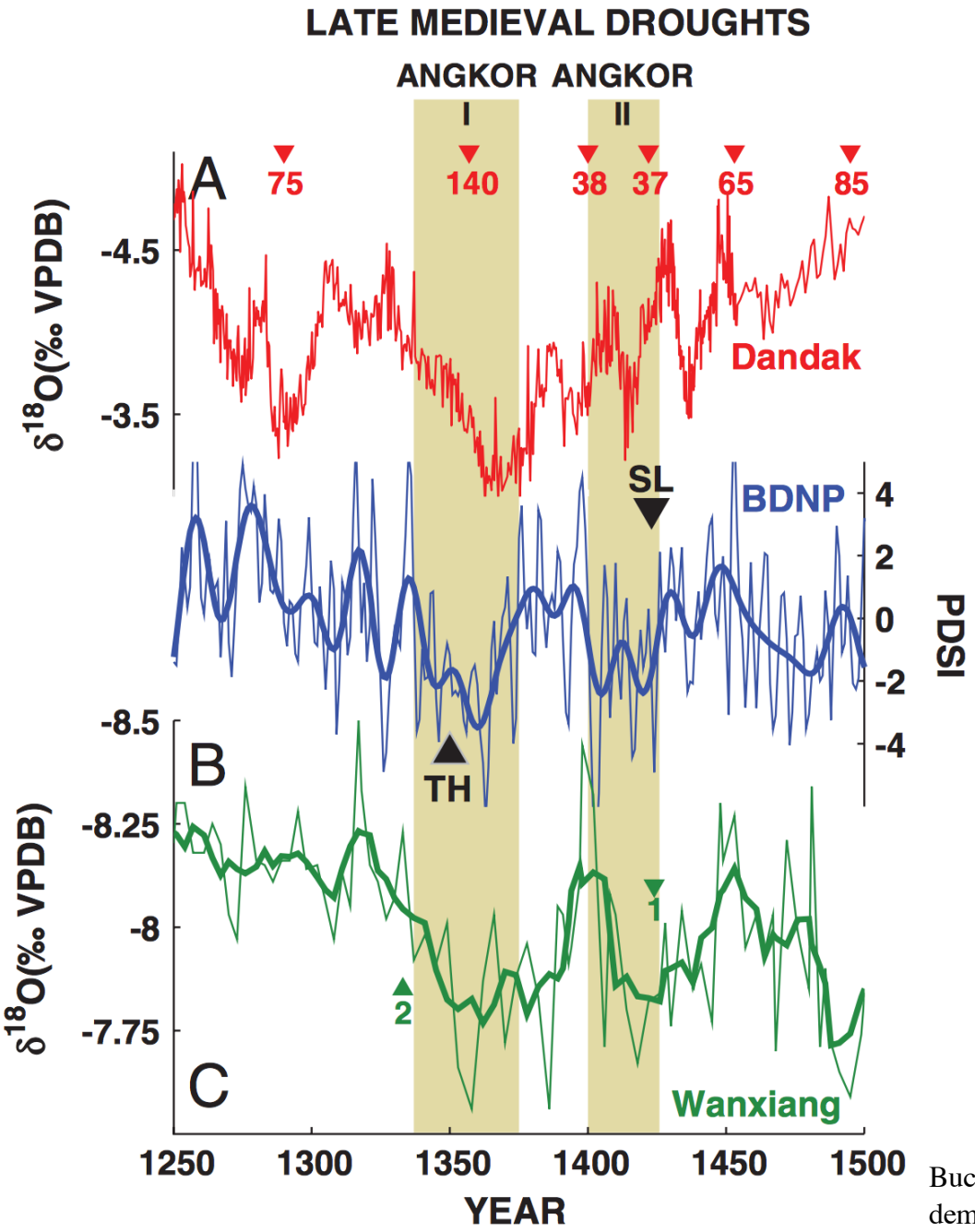
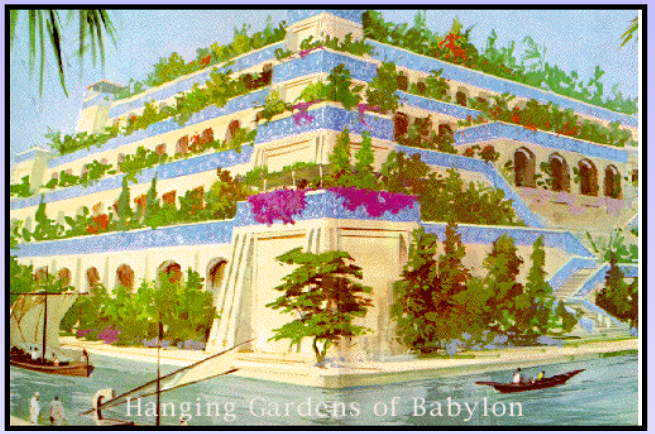


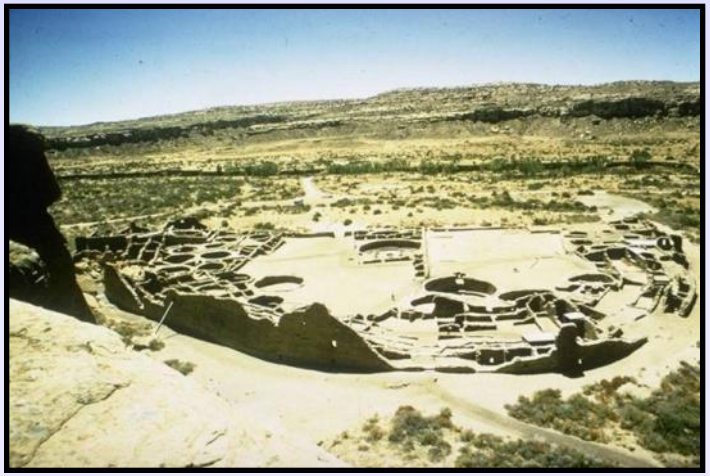
Fig. 3. Regional paleoclimate records of Medieval Drought in Southeast Asia.

Buckley, et al, 2010. Climate as a contributing factor in the demise of Angkor, Cambodia: PNAS, vol. 107 no. 15

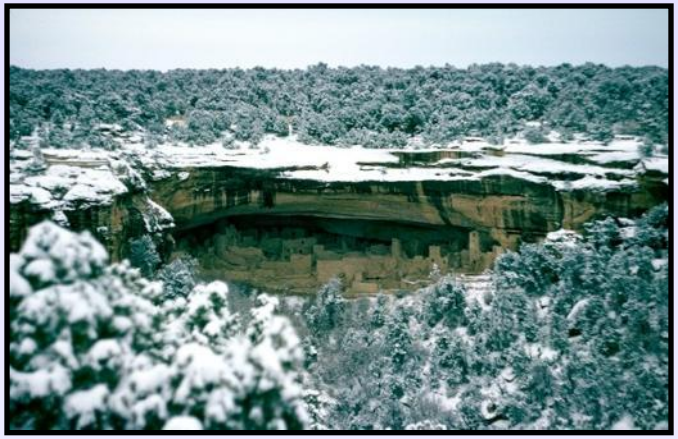
Easter Island

Mesopotamia



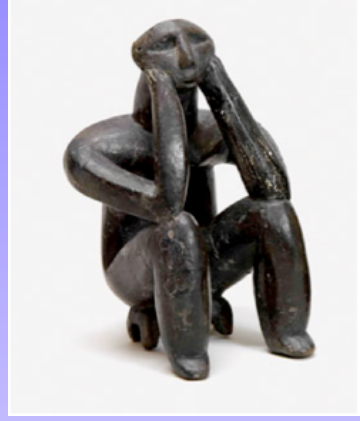


Puebloans-
Anasazi



Summary

Let's think
What does this mean?
What should we do?



Key Points:

- Anatomically modern humans emerge about 130K years ago
- Agriculture and complex societies only develop after climate abruptly stabilizes 11, 570 years ago
- Minor climate variations contribute to transition out of Sahara, demise of Egypt's Old Kingdom, demise of the Mayan Empire, abandonment of Ankgor Wat
- It is unlikely a coincidence that social changes occurred simultaneously with climate changes
- deMenocal (Science, 2001) shows multidecadal to century scale drought are associated with population dislocations, urban abandonment, and even state collapse
- Weiss, et al., (Science, 2001) analyze "What drives societal collapse?" drought a key issue
- Are current climate variations regional/decadal perturbations? Beginnings of a state change? I don't think we know…….

Interesting Reading

- **Two Mile Time Machine**: Richard Alley-U Penn
- **Ice-core evidence of abrupt climate changes:** Alley, R. B., 1997, PNAS 1331–1334, doi: 10.1073/pnas.97.4.1331
- **Earth's Climate, Past and Future:** William Ruddiman-U Virginia
- **The Great Warming, The Long Summer, The Little Ice Age**, others: Brian Fagan-UCSB
- **The Glacial World According to Wally**: Wallace Broecker-Columbia
  - PDF online @
  - http://www.ldeo.columbia.edu/~broecker/Home_files/GlacialWorld.pdf
- **Climate Change in Prehistory: The End of the Reign of Chaos:** William Burroughs
- **Planetary boundaries: Guiding human development on a changing planet :** William Steffen, et al., / sciencemag.org/content/early/recent/ 15 January 2015 / Page 2 / 10.1126/science.1259855
- **Alan Robock, Rutgers University:** http://www.envsci.rutgers.edu/~robock/
- **JPL/NASA climate website:** http://climate.nasa.gov/keyIndicators/

Any Questions?

FIRST INTERMEDIATE PERIOD STELAE (2160-2055 BC)

Anktifi of Mo'alla:

"All of Upper Egypt was dying of hunger and each individual had reached such a state of hunger that he ate his own children."

Merer of Edfu:

"I buried the dead and I nourished the living, wherever I went in the drought that occurred."

Prophesy of Neferti:

"Dry is the river of Egypt, one crossed the water on foot; one seeks water for ships to sail on, its course having turned into shore land."

Nomarch Khety:

"I made a sluice-way for this town, while Upper Egypt was in a bad way, no water to be seen…every neighborhood thirsted."

The entire Fayoum dried up—
this has not happened since.