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IAEA
International Atomic Energy Agency

2464-7

Earthquake Tectonics and Hazards on the Continents

17 - 28 June 2013

Asia, Himalaya & China tectonics and hazard

S. G. Wesnousky
Univ. of Nevada
USA

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it
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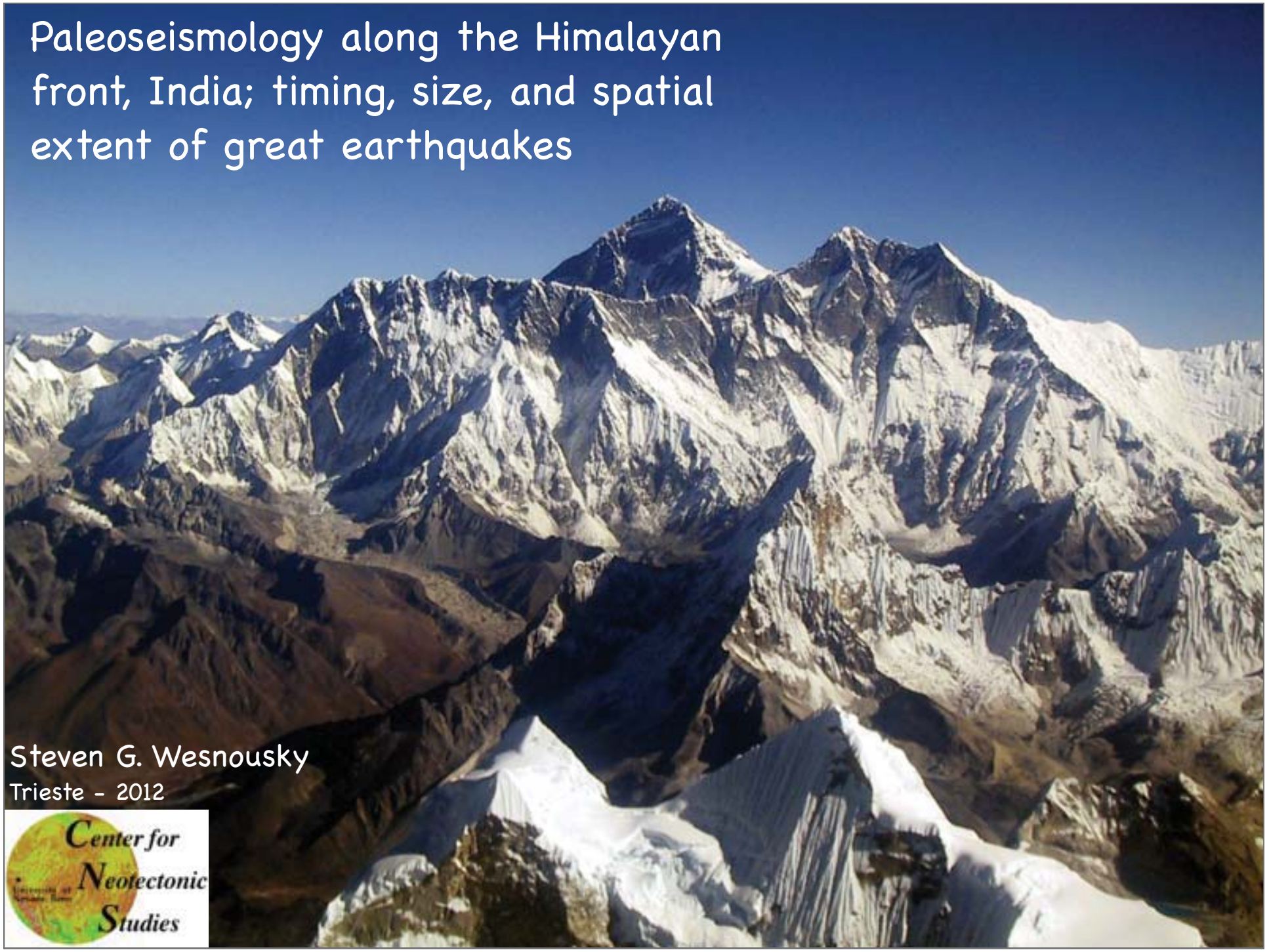
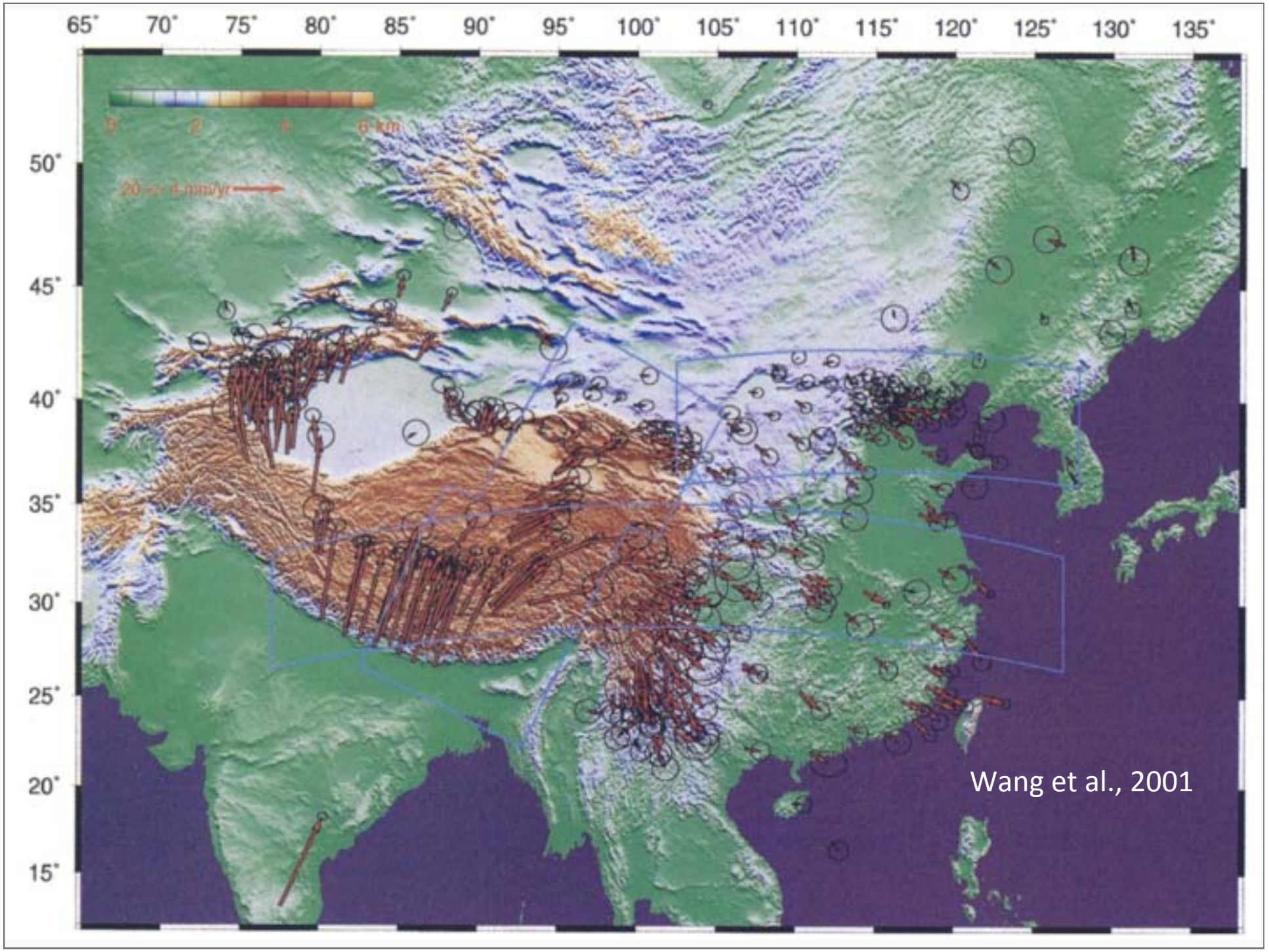
Paleoseismology along the Himalayan front, India; timing, size, and spatial extent of great earthquakes

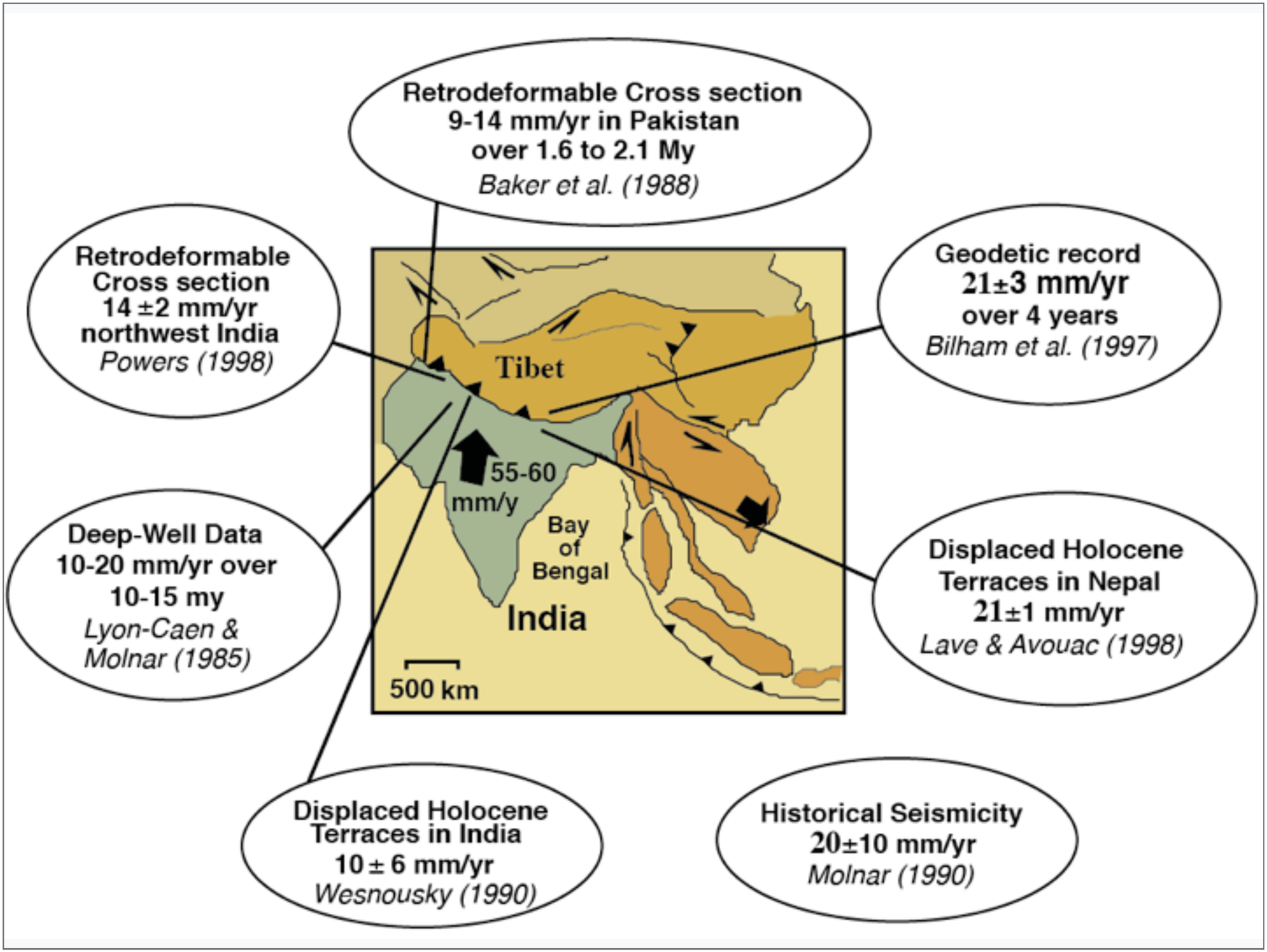


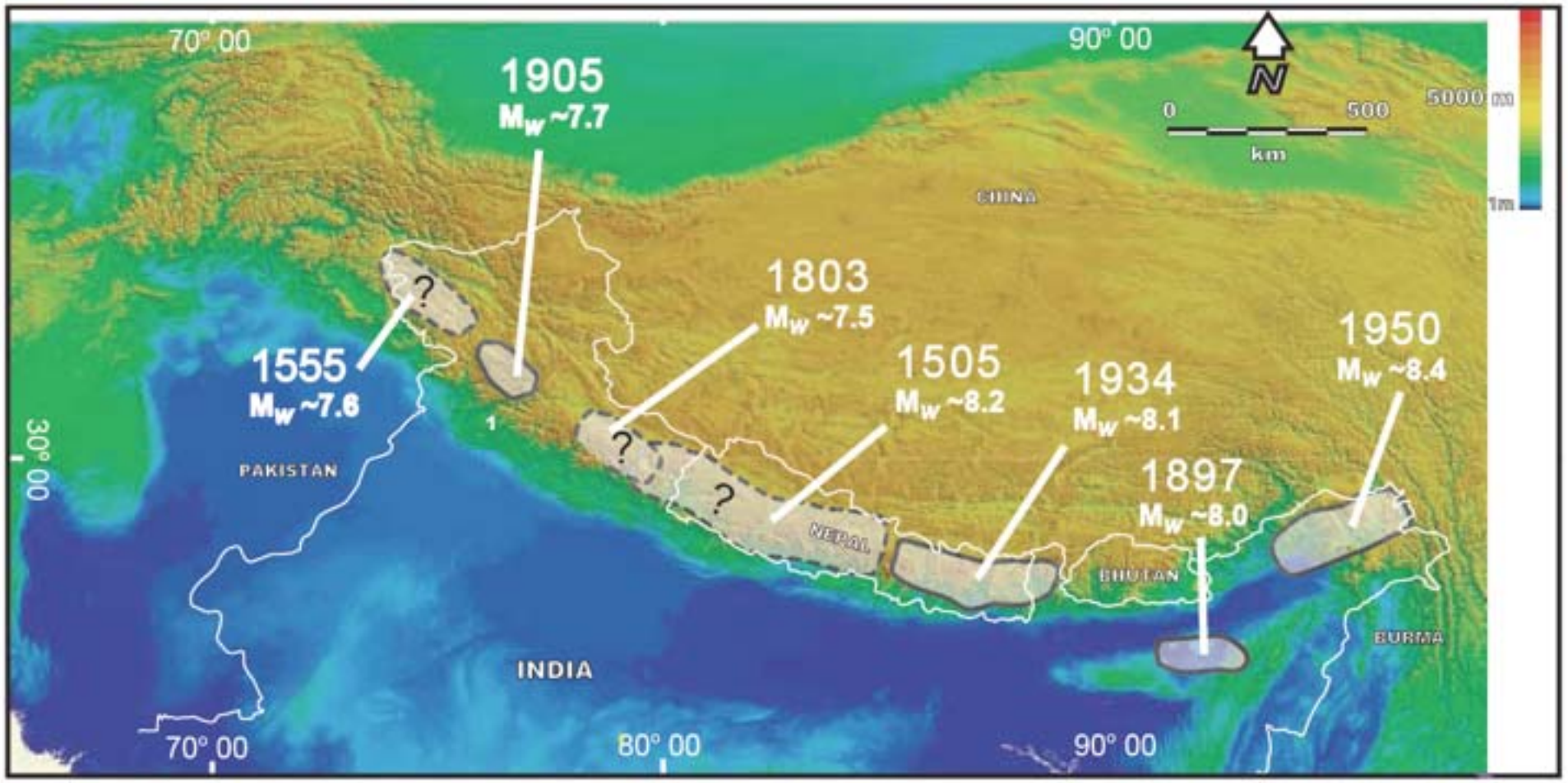
Steven G. Wesnousky

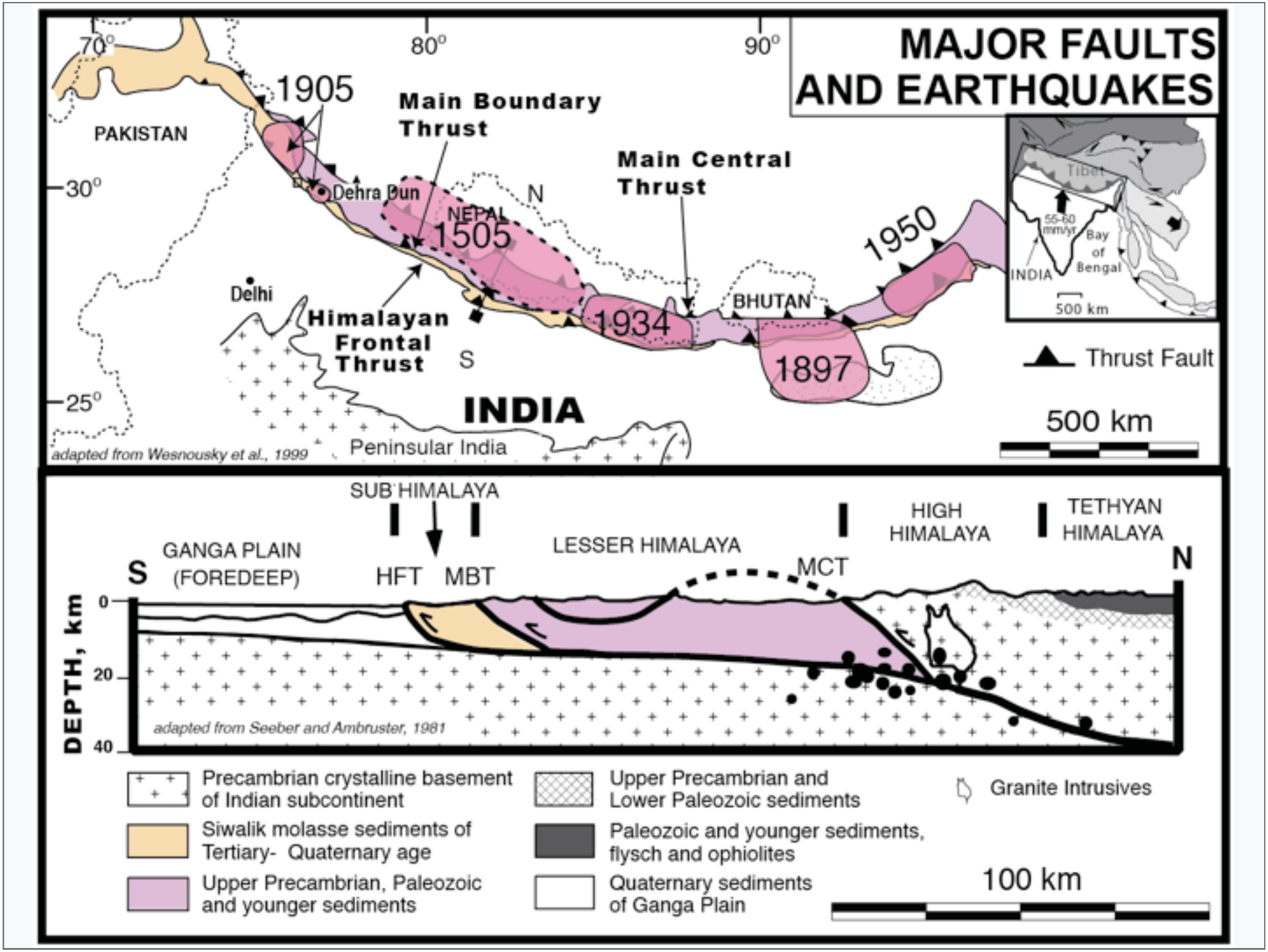
Trieste - 2012

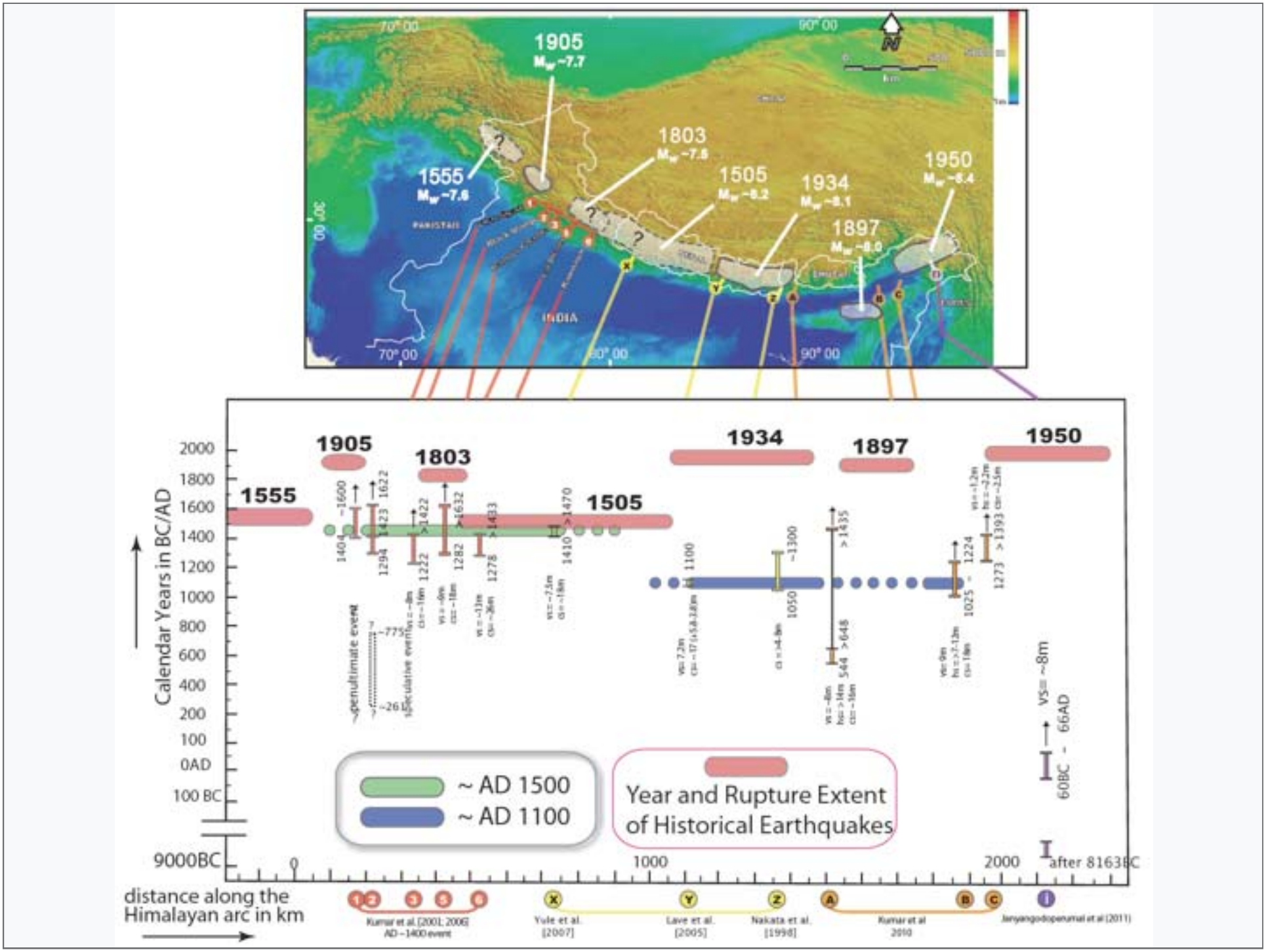
Center for Neotectonic Studies

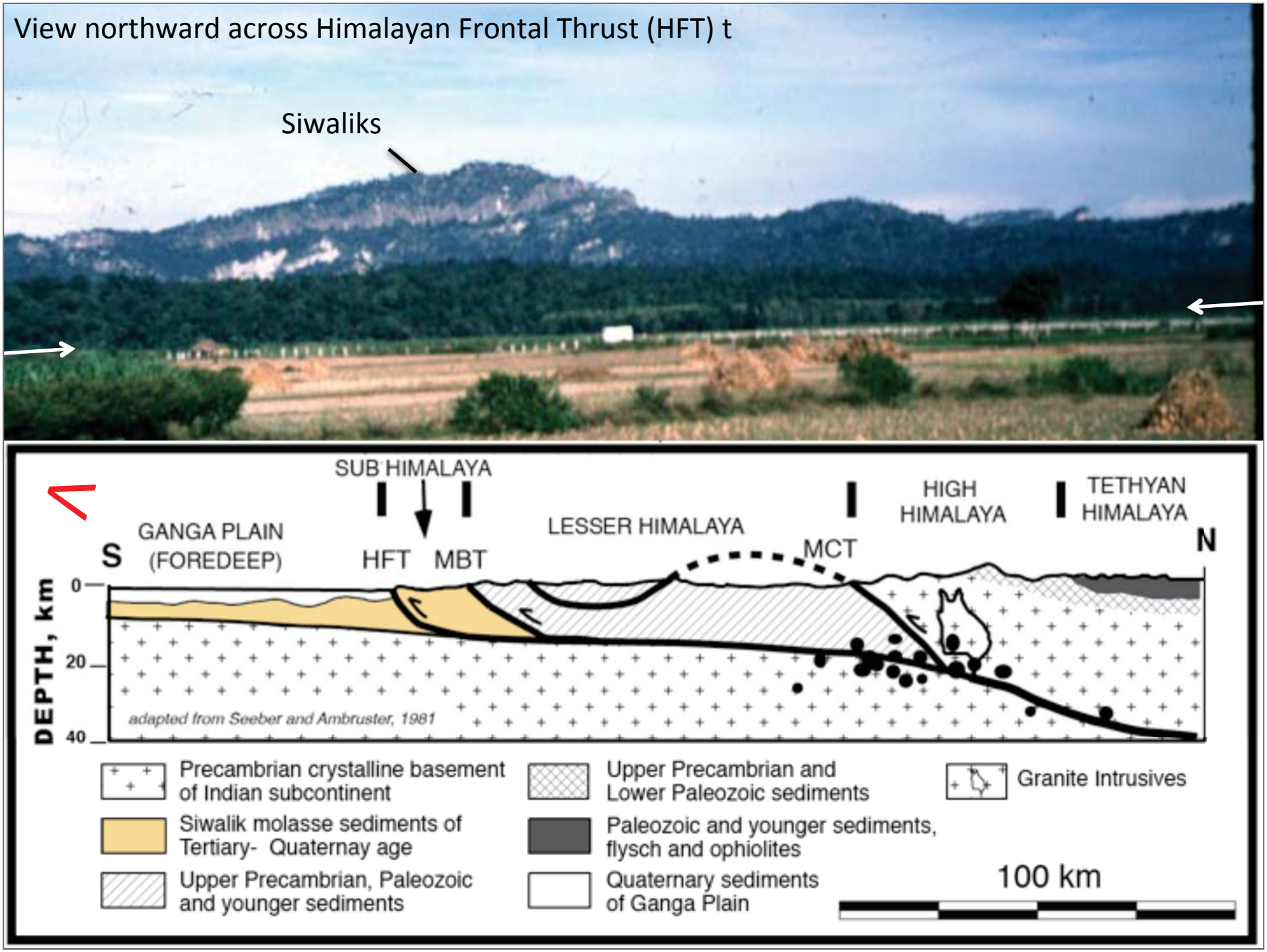

65° 70° 75° 80° 85° 90° 95° 100° 105° 110° 115° 120° 125° 130° 135°
50° 45° 40° 35° 30° 25° 20° 15°
Wang et al., 2001

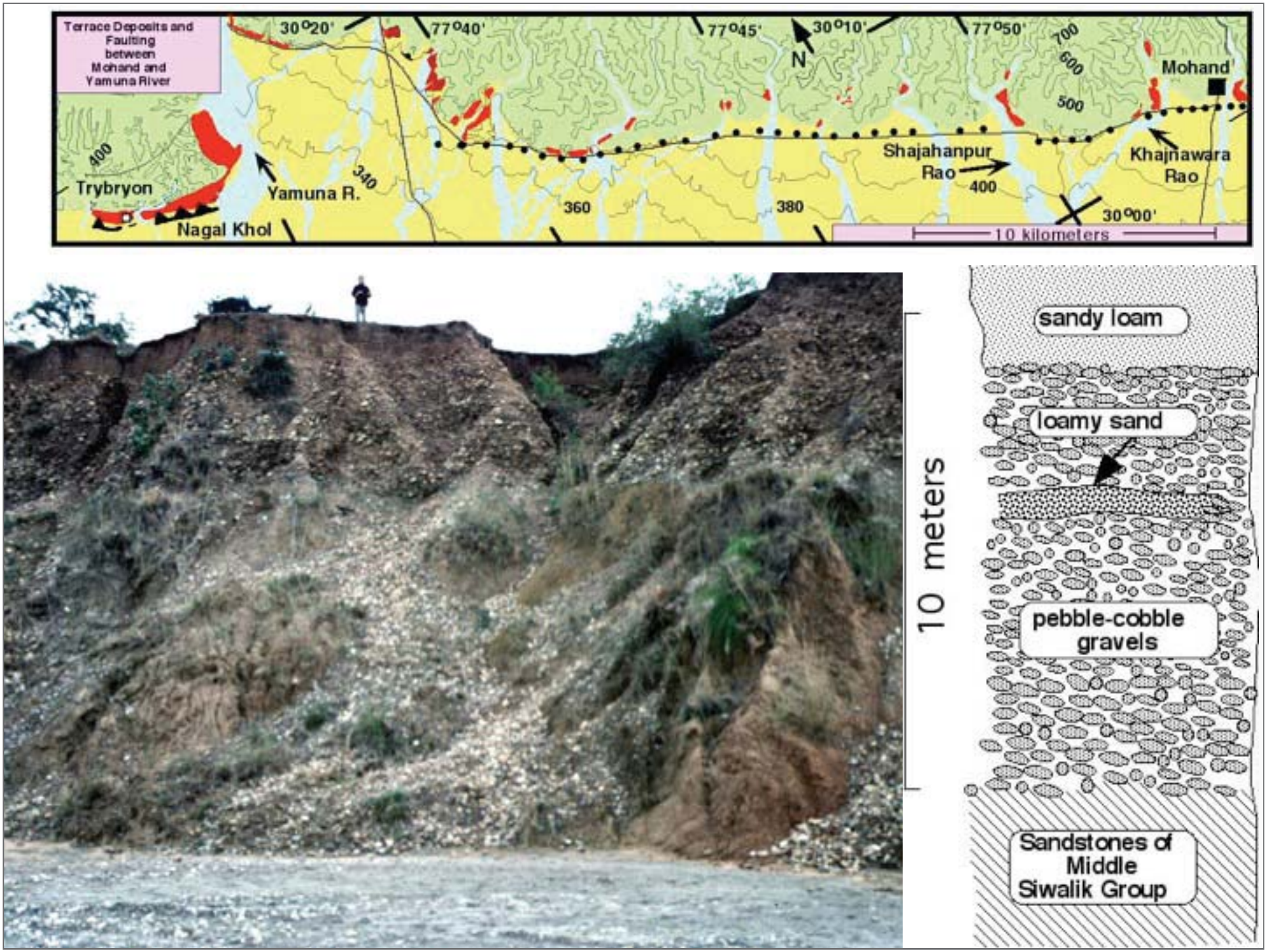

Retrodeformable Cross section
9-14 mm/yr in Pakistan
over 1.6 to 2.1 My
Baker et al. (1988)
Retrodeformable
Cross section
14 ±2 mm/yr
northwest India
Powers (1998)
Geodetic record
21±3 mm/yr
over 4 years
Bilham et al. (1997)
Tibet
55-60
mm/y
Bay
of
Bengal
India
500 km
Deep-Well Data
10-20 mm/yr over
10-15 my
Lyon-Caen &
Molnar (1985)
Displaced Holocene
Terraces in Nepal
21±1 mm/yr
Lave & Avouac (1998)
Displaced Holocene
Terraces in India
10 ± 6 mm/yr
Wesnousky (1990)
Historical Seismicity
20±10 mm/yr
Molnar (1990)

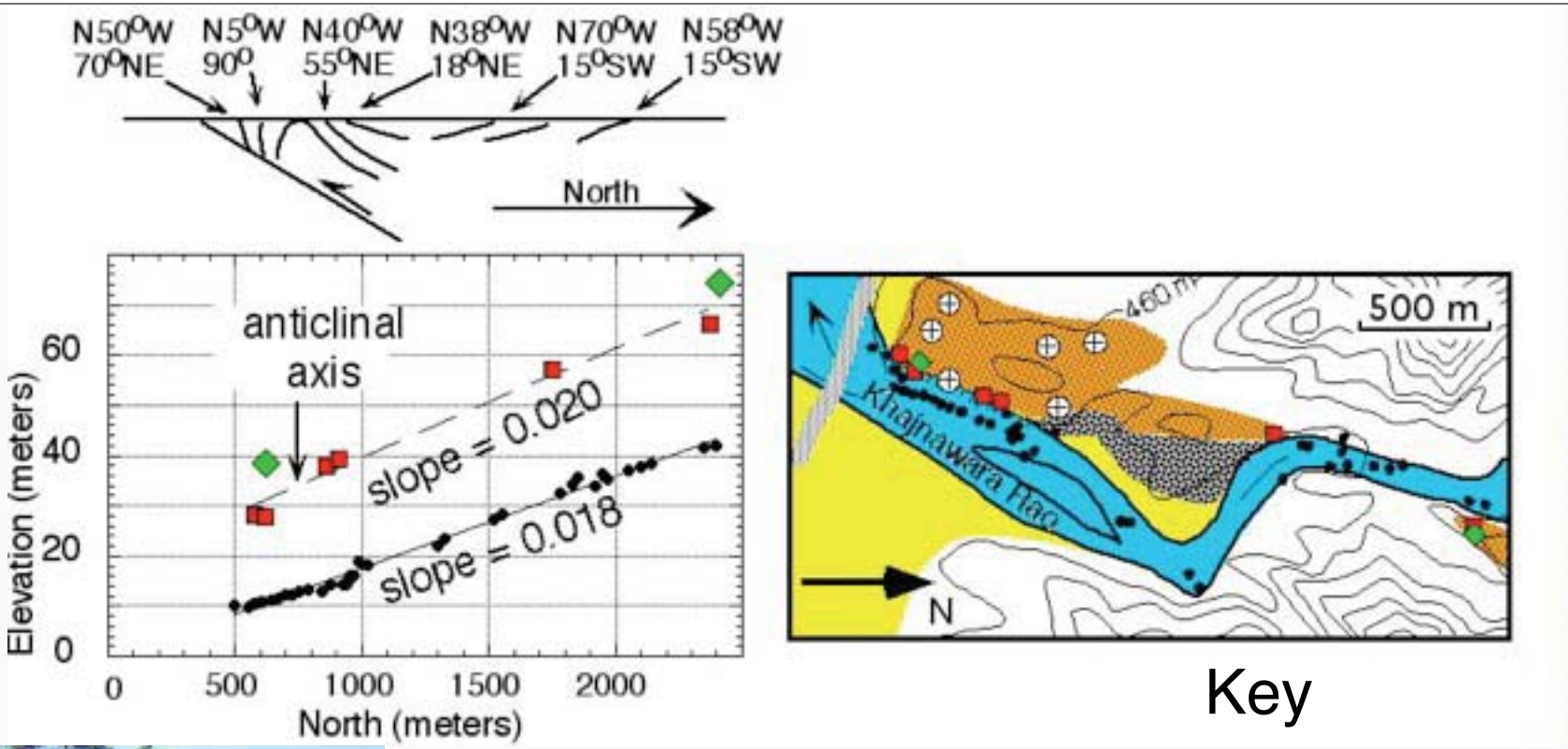

70° 00
90° 00
N
0
500
km
5000 m
1m
1905
M_W ~7.7
1803
M_W ~7.5
1555
M_W ~7.6
1505
M_W ~8.2
1934
M_W ~8.1
1950
M_W ~8.4
1897
M_W ~8.0
?
1
CHINA
PAKISTAN
NEPAL
BHUTAN
BURMA
INDIA
30° 00
70° 00
80° 00
90° 00


MAJOR FAULTS AND EARTHQUAKES
70°
80°
90°
30°
25°
PAKISTAN
1905
Main Boundary Thrust
Main Central Thrust
Dehra Dun
NEPAL
1505
N
1950
Delhi
Himalayan Frontal Thrust
S
1934
BHUTAN
1897
INDIA
Peninsular India
adapted from Wesnousky et al., 1999
Tibet
55-60 mm/yr
Bay of Bengal
INDIA
500 km
Thrust Fault
500 km
SUB HIMALAYA
GANGA PLAIN (FOREDEEP)
HFT
MBT
LESSER HIMALAYA
MCT
HIGH HIMALAYA
TETHYAN HIMALAYA
S
N
DEPTH, km
0
20
40
adapted from Seeber and Ambruster, 1981
Precambrian crystalline basement of Indian subcontinent
Siwalik molasse sediments of Tertiary- Quaternary age
Upper Precambrian, Paleozoic and younger sediments
Upper Precambrian and Lower Paleozoic sediments
Paleozoic and younger sediments, flysch and ophiolites
Quaternary sediments of Ganga Plain
Granite Intrusives
100 km


1905
M_w ~7.7
1803
M_w ~7.5
1555
M_w ~7.6
1505
M_w ~8.2
1934
M_w ~8.1
1950
M_w ~8.4
1897
M_w ~8.0
INDIA
PAKISTAN
70° 00
90° 00
30° 00
1555
1905
1803
1505
1934
1897
1950
Calendar Years in BC/AD
2000
1800
1600
1400
1200
1000
800
600
400
200
100
0AD
100 BC
9000BC
penultimate event
speculative event
~ AD 1500
~ AD 1100
Year and Rupture Extent
of Historical Earthquakes
vs= ~8m
66AD
60BC
after 8163BC
1000
2000
distance along the
Himalayan arc in km
Kumar et al.[2001; 2006]
AD ~1400 event
Yule et al.
[2007]
Lave et al.
[2005]
Nakata et al.
[1998]
Kumar et al
2010
Jayangondaperumal et al (2011)


View northward across Himalayan Frontal Thrust (HFT) t
Siwaliks
SUB HIMALAYA
GANGA PLAIN
(FOREDEEP)
S
HFT
MBT
LESSER HIMALAYA
MCT
HIGH
HIMALAYA
TETHYAN
HIMALAYA
N
DEPTH, km
0
20
40
adapted from Seeber and Ambruster, 1981
Precambrian crystalline basement
of Indian subcontinent
Siwalik molasse sediments of
Tertiary- Quaternay age
Upper Precambrian, Paleozoic
and younger sediments
Upper Precambrian and
Lower Paleozoic sediments
Paleozoic and younger sediments,
flysch and ophiolites
Quaternary sediments
of Ganga Plain
Granite Intrusives
100 km


Terrace Deposits and Faulting between Mohand and Yamuna River
30°20'
77°40'
77°45'
30°10'
77°50'
N
700
600
500
Mohand
400
Trybryon
Yamuna R.
340
360
380
Shajahanpur Rao
400
Khajnawara Rao
30°00'
Nagal Khol
10 kilometers
10 meters
sandy loam
loamy sand
pebble-cobble gravels
Sandstones of Middle Siwalik Group



Key

Bedrock Insision ~20m

Radiocarbon Sample
B.C. 1880 - 1450

uplift rate ~5-6 mm/yr

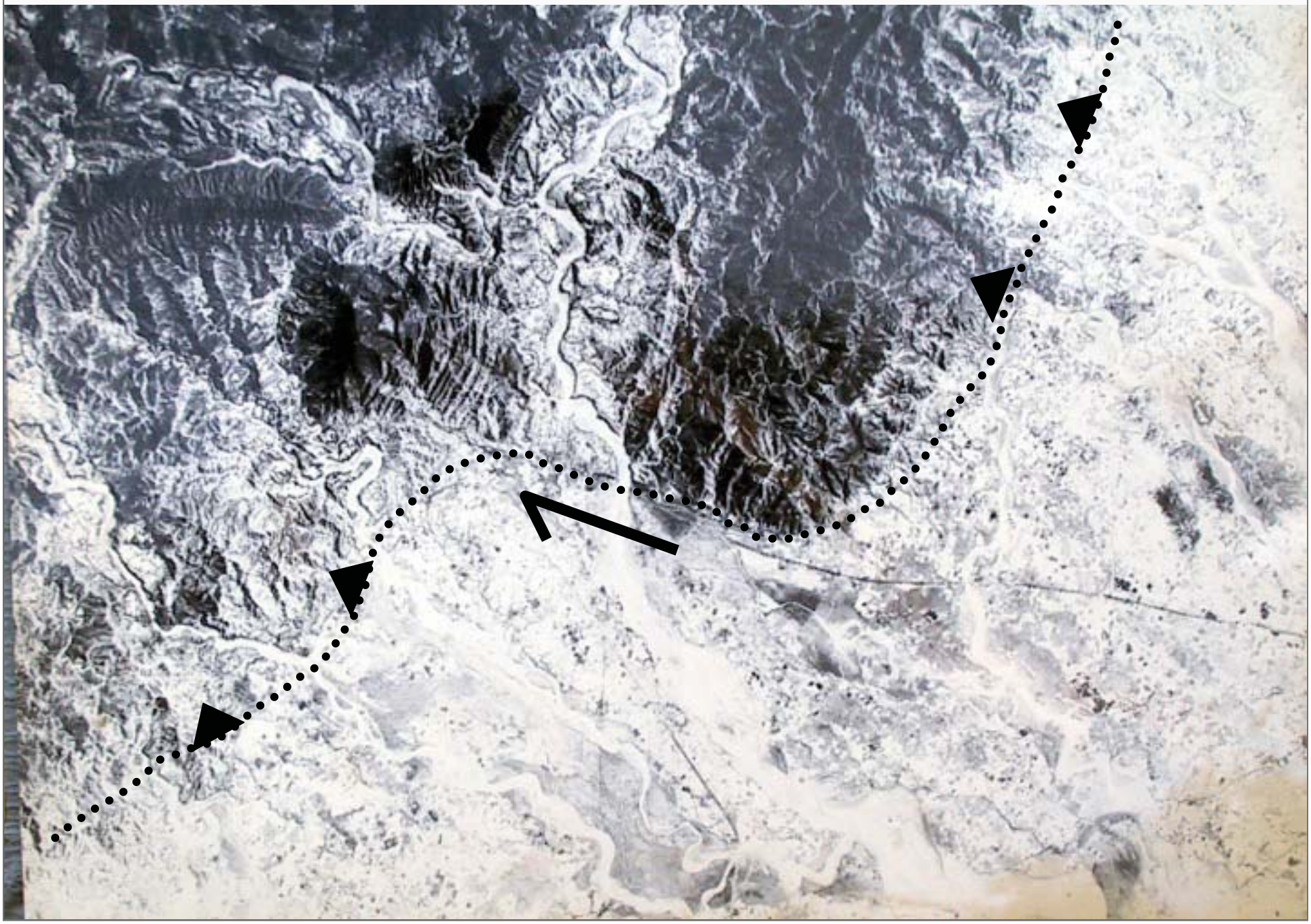
10-12 mm/yr slip rate
assuming 30° dip

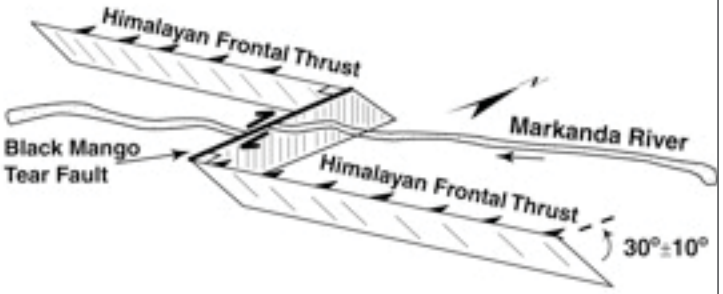
Survey Points
- River grade
- Base of terrace deposits
- Surface of terrace deposits

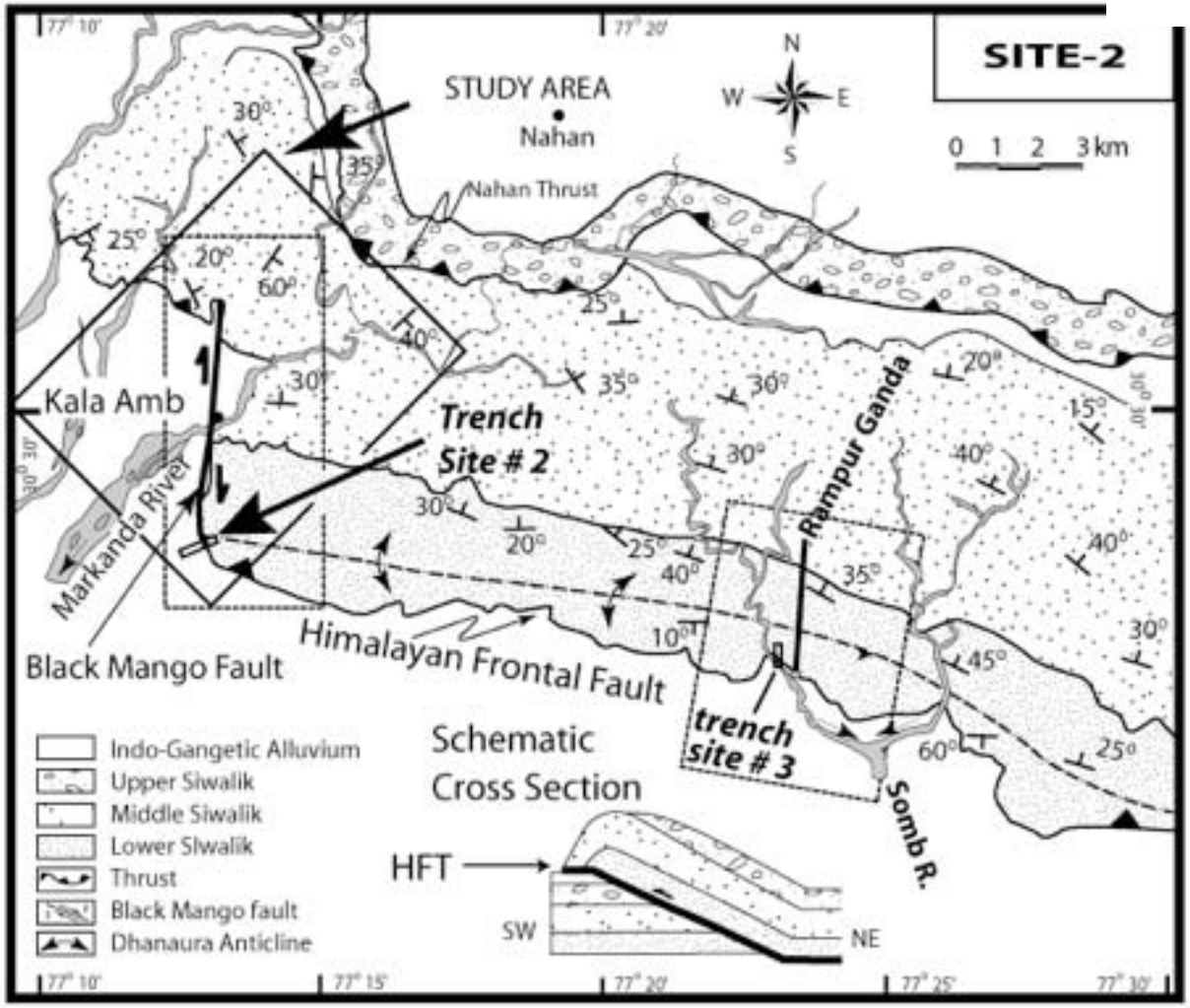
Forest road & inferred trace of HFT

- Lower terrace deposit
- High terrace deposits
- Soil pits and auger holes
- Active Wash
- Active Fan

Site 2 - near Kala Amb (Black Mango) and Markanda River - a tear fault along the HFT




Himalayan Frontal Thrust
Markanda River
Black Mango
Tear Fault
Himalayan Frontal Thrust
30°±10°


SITE-2
STUDY AREA
Nahan
N
W
E
S
0 1 2 3 km
Nahan Thrust
Kala Amb
Trench
Site # 2
Markanda River
Rampur Ganda
Black Mango Fault
Himalayan Frontal Fault
trench
site # 3
Somb R.
Schematic
Cross Section
HFT
SW
NE
Indo-Gangetic Alluvium
Upper Siwalik
Middle Siwalik
Lower Siwalik
Thrust
Black Mango fault
Dhanaura Anticline
77° 10'
77° 15'
77° 20'
77° 25'
77° 30'

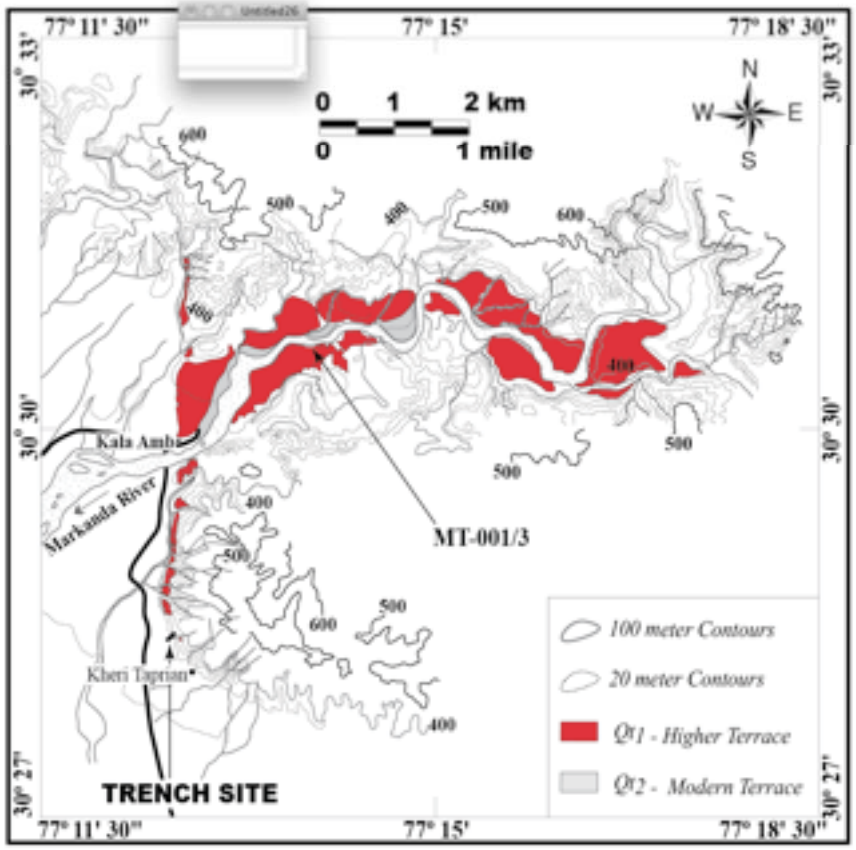

SIWALIKS
Kala Amb
Markanda River
Terraces
TRENCH
SITE
Kheri Teprian
0 1 2 3 km

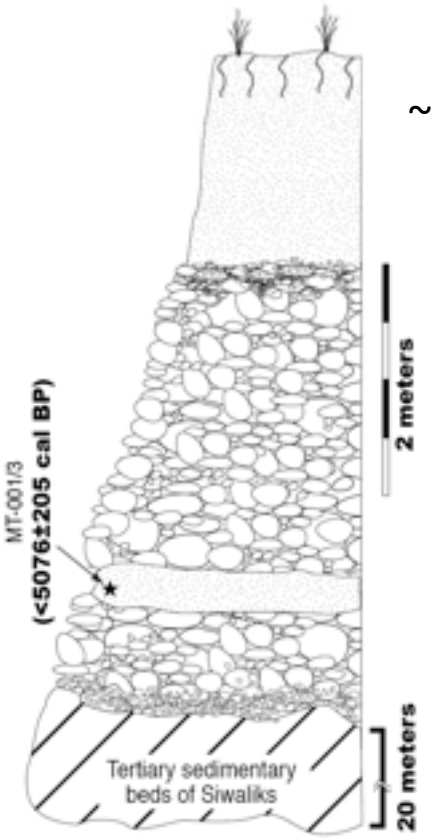
Strath:
~20 m above riverbed

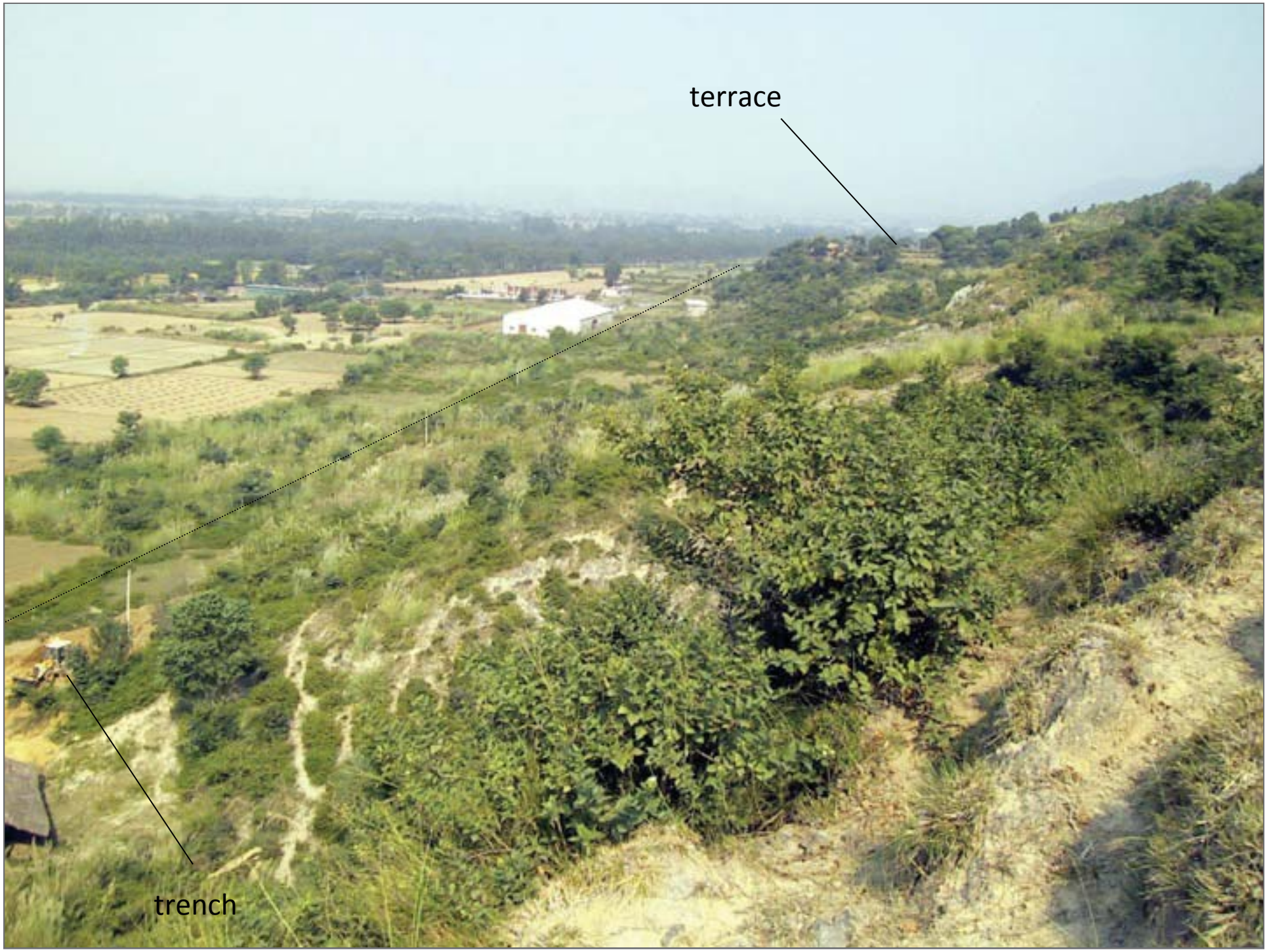
Radiocarbon:
3015 – 2878 B.C

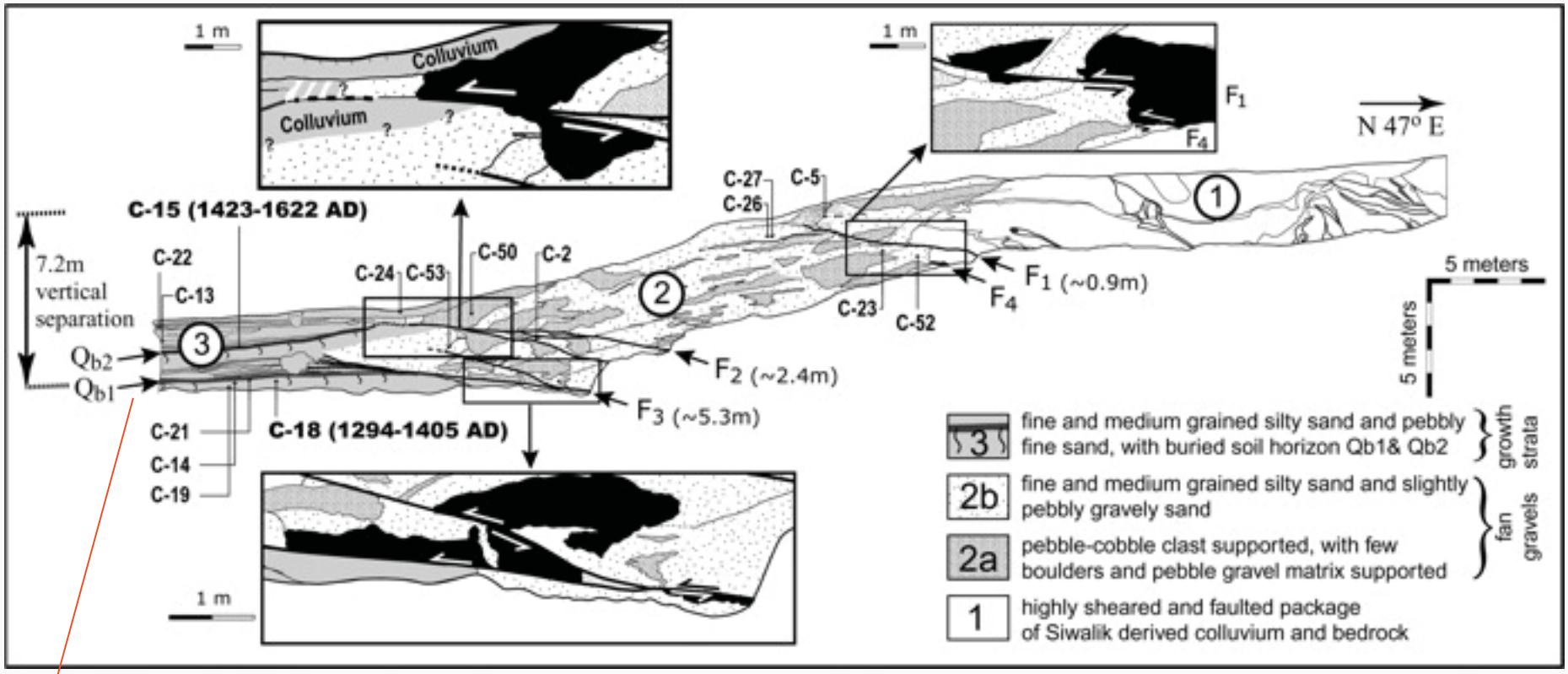
Uplift Rate:
~ 4mm/yr

Slip Rate
~ 8mm/yr on 30° dipping fault






terrace
trench



Critical observations:
Qb1 and Qb2 are buried soils (A-horizons)
Qb1 is cut by fault F3
Colluvium, growth strata, and development of Qb2 develop on Qb1
Qb2 displaced by fault F2
Subsequent development of growth strata

Fault displacements = 8.6 m yield only ~ 1m vert sep

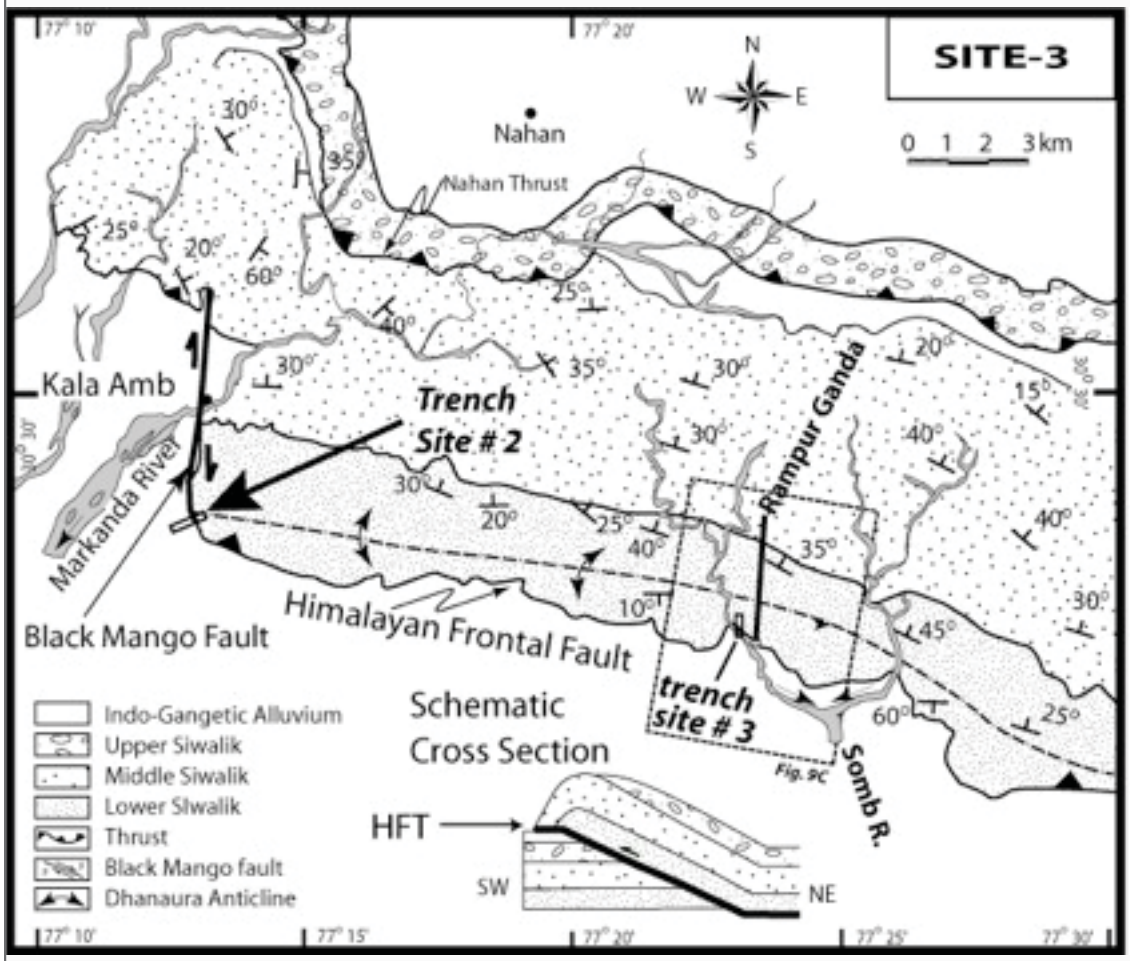
Vert sep = 7.2 m

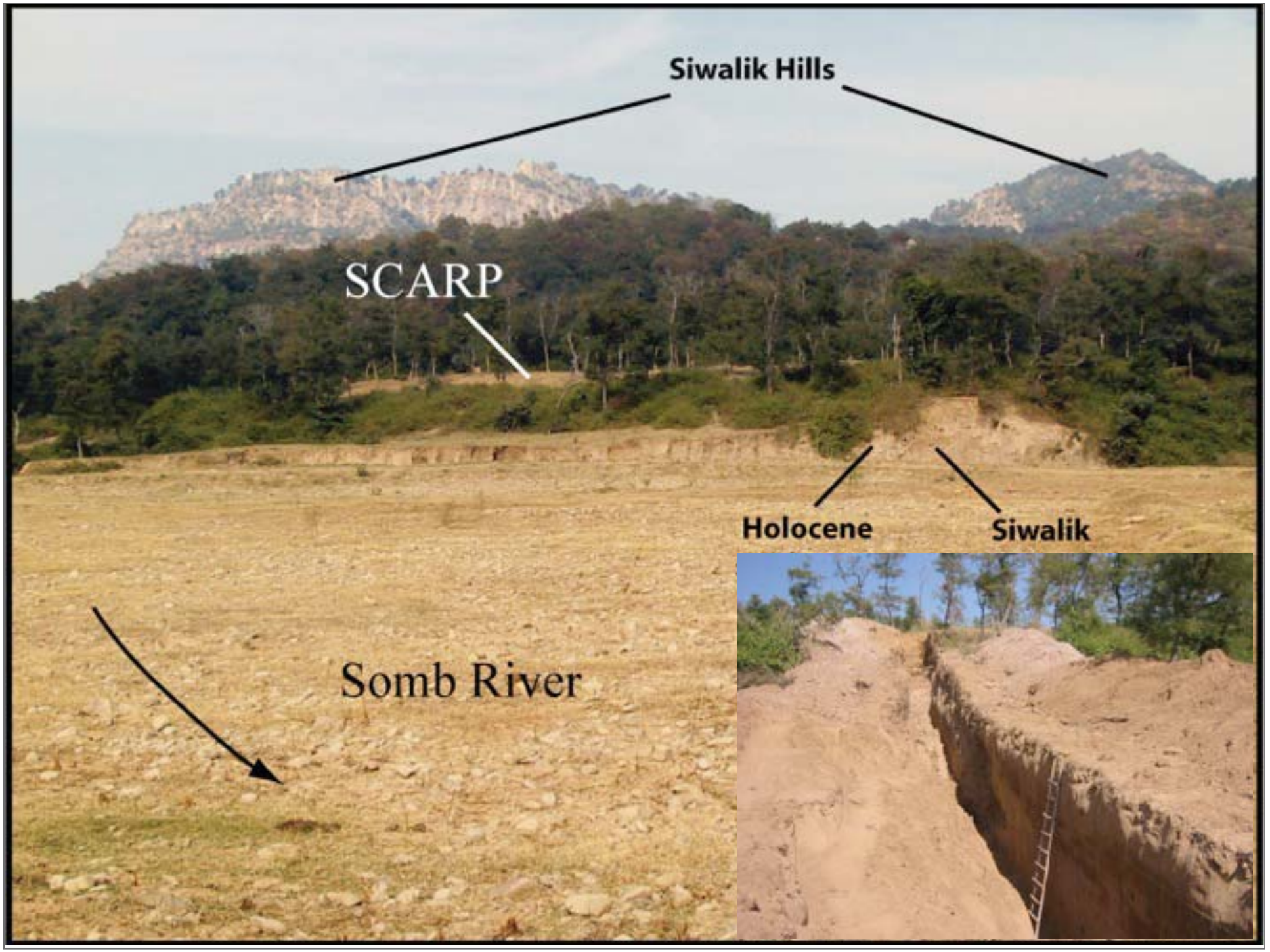
7.2m/sin(30) ~ 14.4 m fault slip

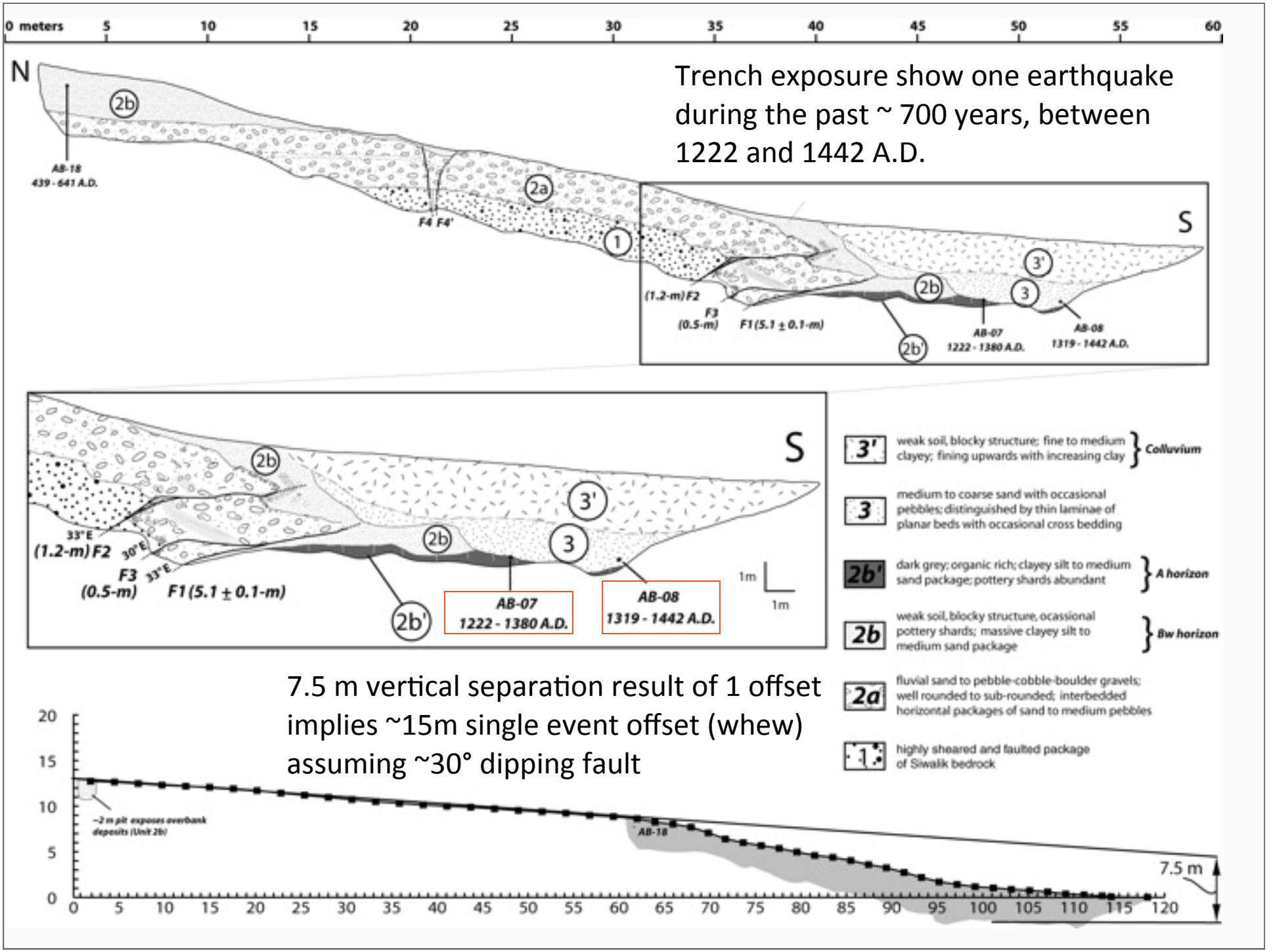
Large amount of slip taken up by warping

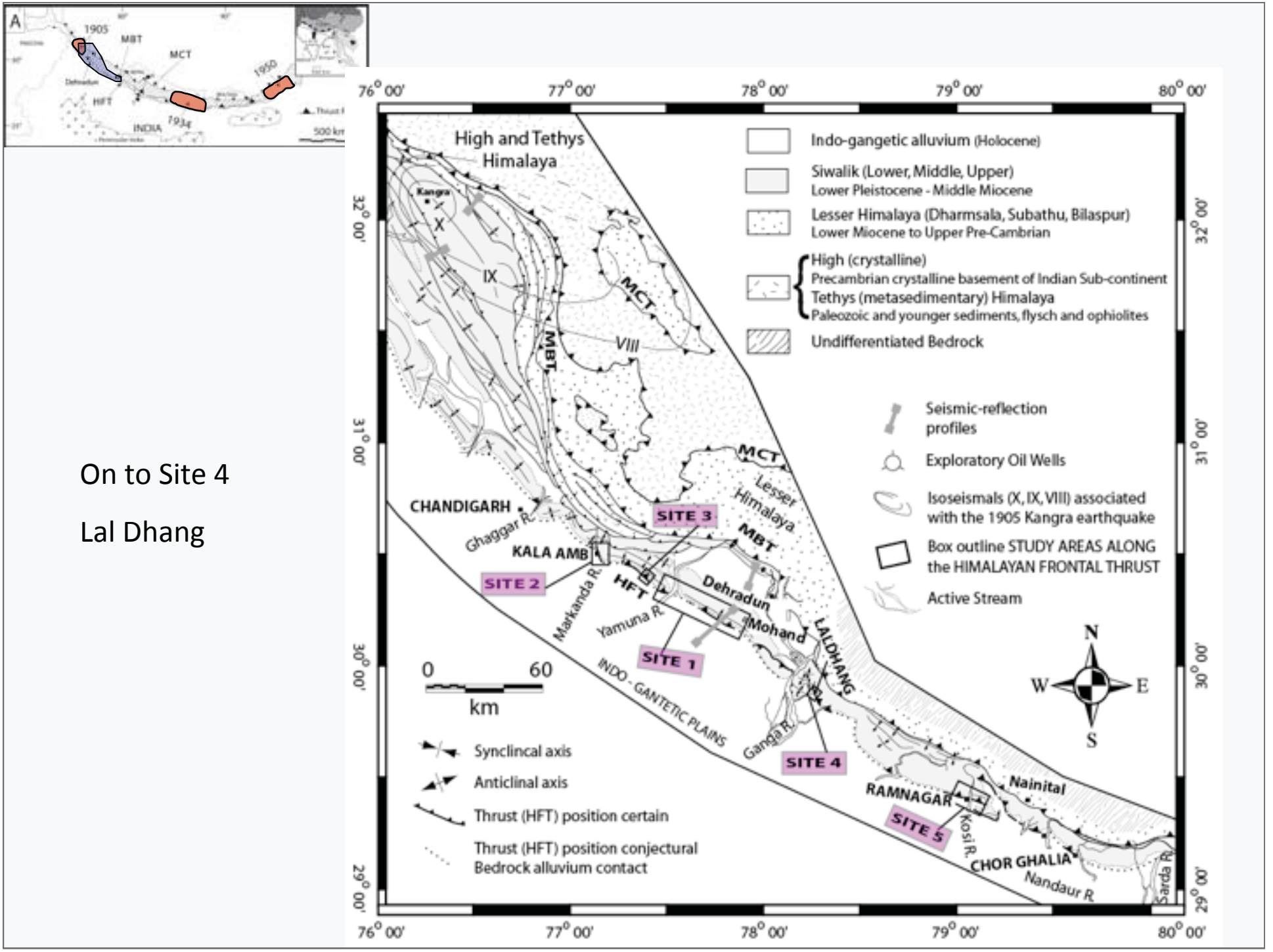
2 events: subsequent to 1294 and 1423 A.D.

Moving eastward to Rampur Ghanda – another trench site




Siwalik Hills
SCARP
Holocene
Siwalik
Somb River

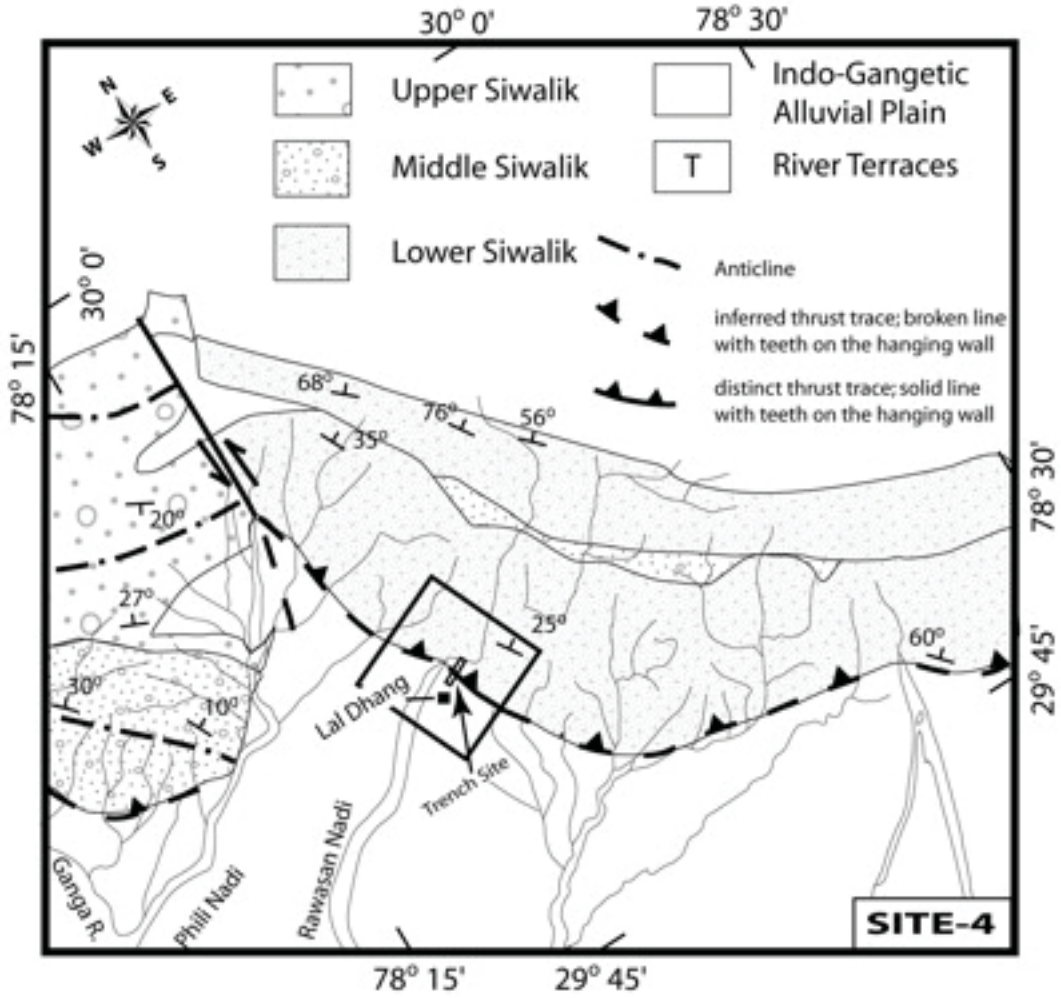

0 meters 5 10 15 20 25 30 35 40 45 50 55 60
N
S
2b
2a
1
3'
3
2b'
AB-18
439 - 641 A.D.
F4 F4'
(1.2-m) F2
F3
(0.5-m)
F1 (5.1 ± 0.1-m)
AB-07
1222 - 1380 A.D.
AB-08
1319 - 1442 A.D.
33°E
30°E
33°E
1m
1m
Trench exposure show one earthquake during the past ~ 700 years, between 1222 and 1442 A.D.
3' weak soil, blocky structure; fine to medium clayey; fining upwards with increasing clay } Colluvium
3 medium to coarse sand with occasional pebbles; distinguished by thin laminae of planar beds with occasional cross bedding
2b' dark grey; organic rich; clayey silt to medium sand package; pottery shards abundant } A horizon
2b weak soil, blocky structure, ocassional pottery shards; massive clayey silt to medium sand package } Bw horizon
2a fluvial sand to pebble-cobble-boulder gravels; well rounded to sub-rounded; interbedded horizontal packages of sand to medium pebbles
1 highly sheared and faulted package of Siwalik bedrock
7.5 m vertical separation result of 1 offset implies ~15m single event offset (whew) assuming ~30° dipping fault
~2 m pit exposes overbank deposits (Unit 2b)
AB-18
7.5 m
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
0 5 10 15 20

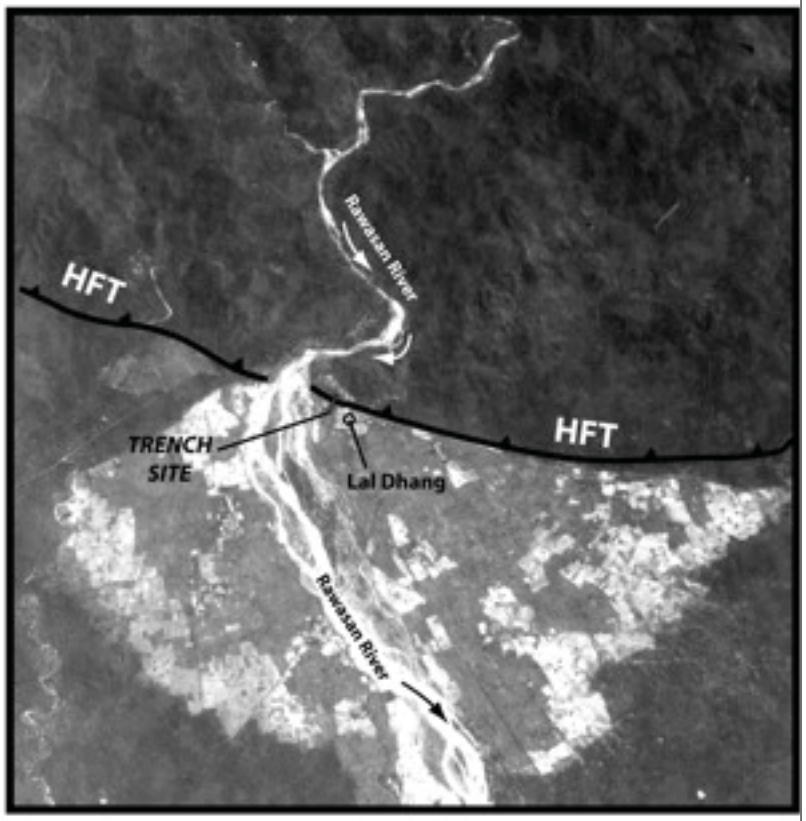


On to Site 4

Lal Dhang

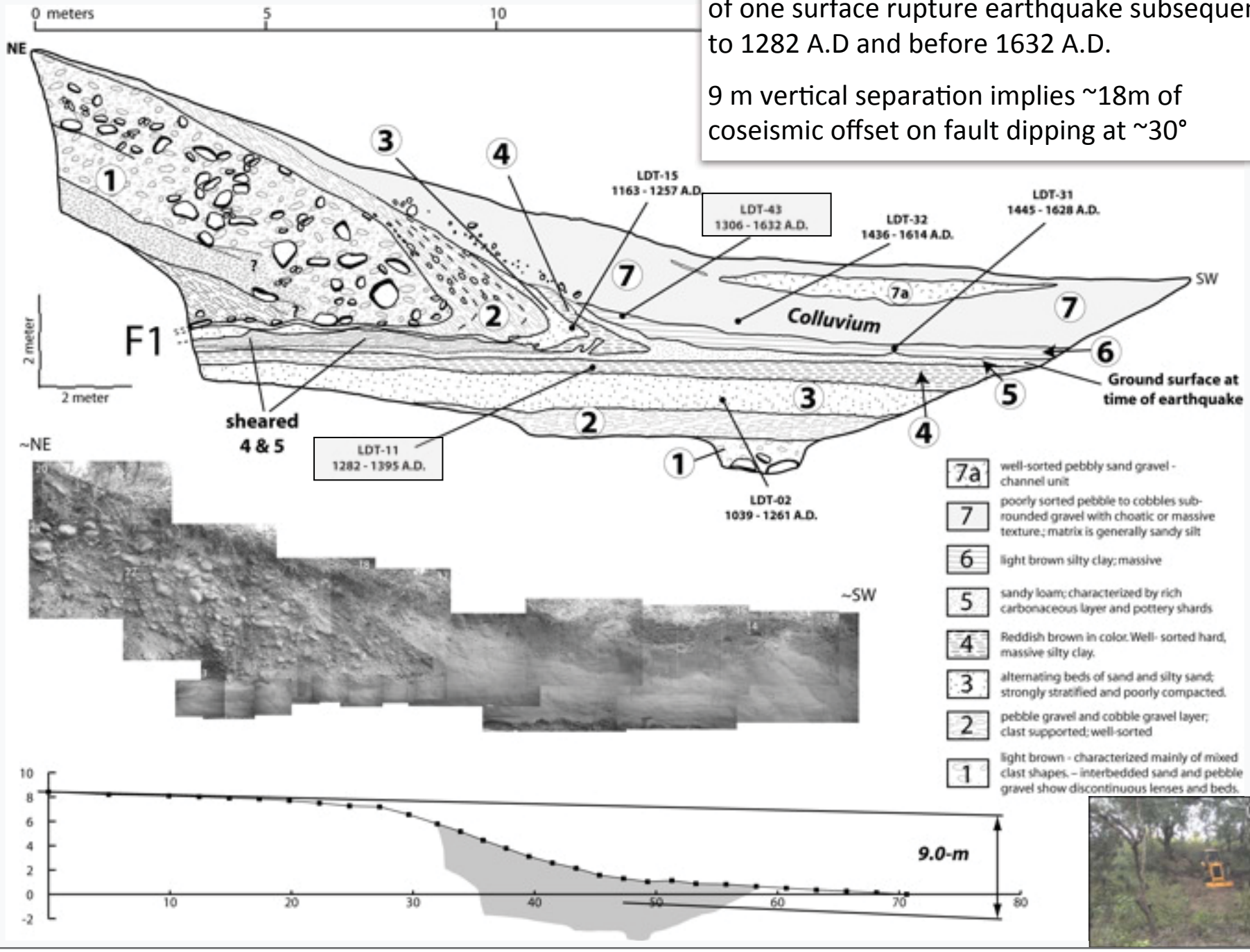
Site 5 - a scarp and trench at Lal Dhang



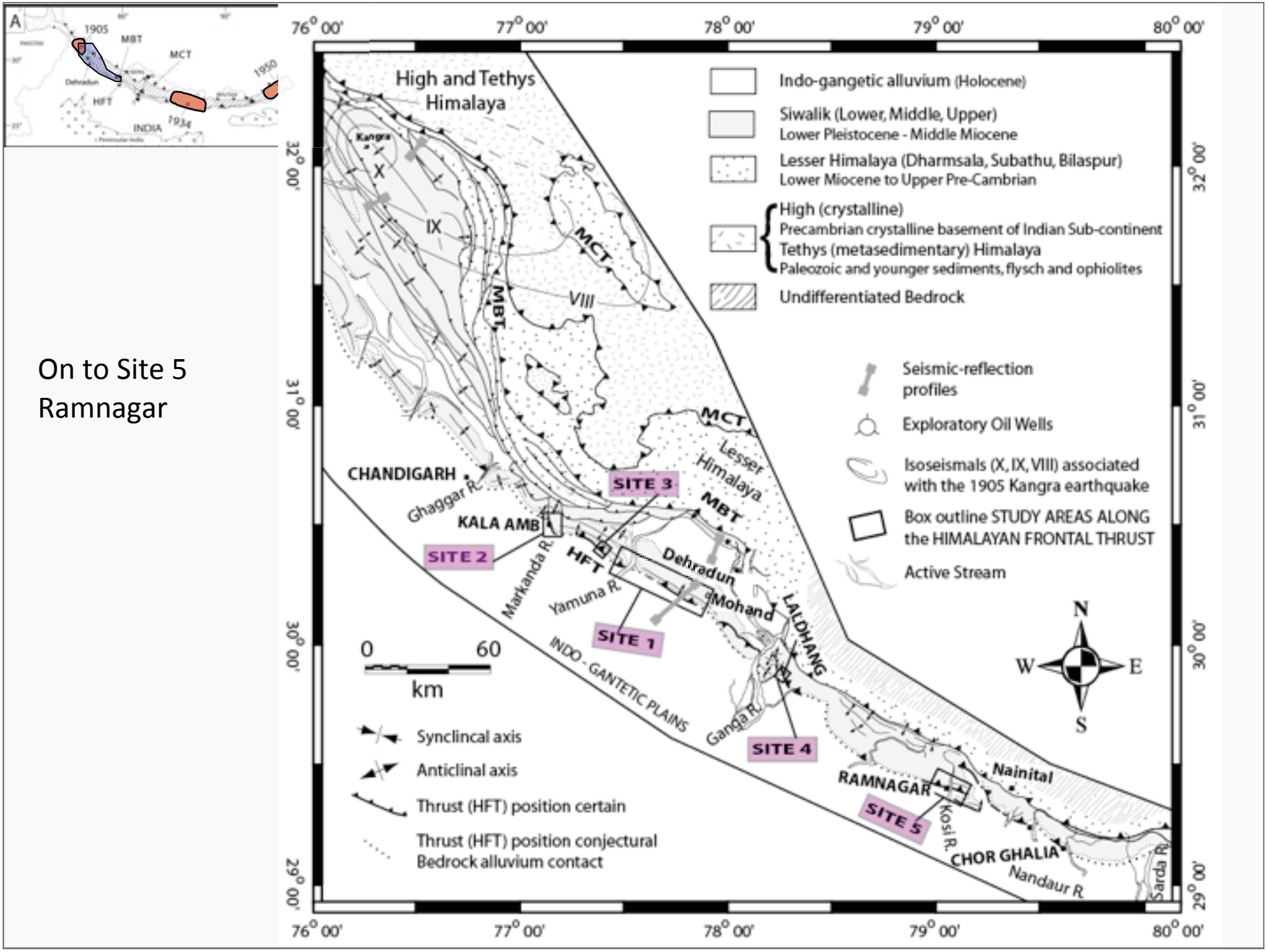


Displacement observed along fault F1 is result of one surface rupture earthquake subsequent to 1282 A.D and before 1632 A.D.

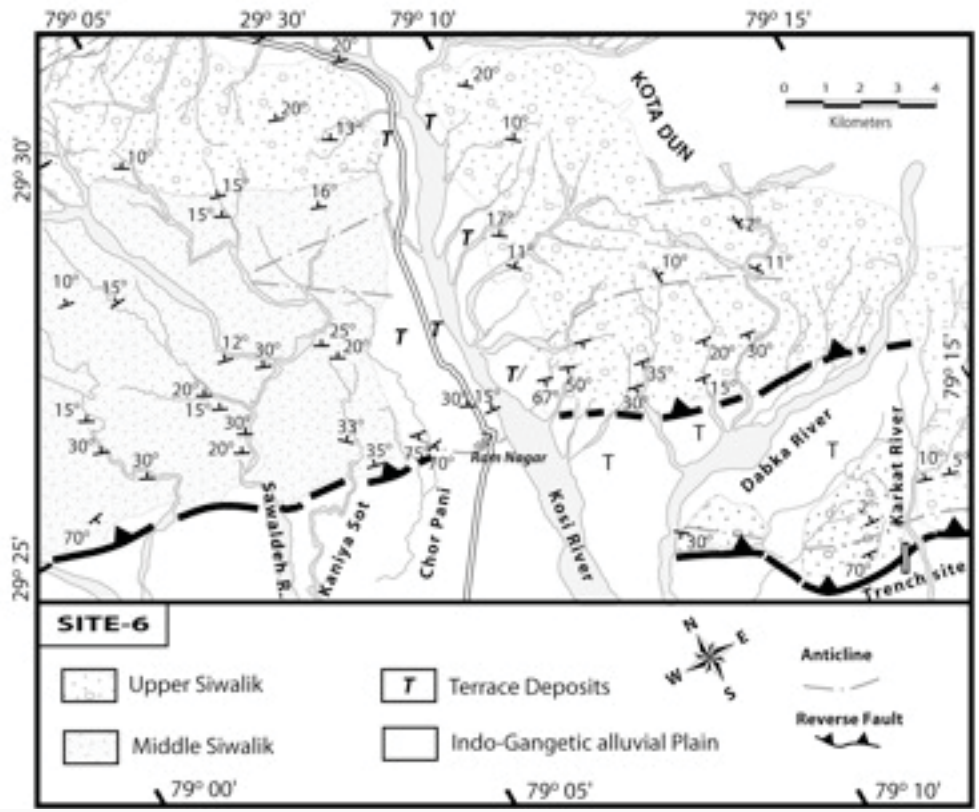
9 m vertical separation implies ~18m of coseismic offset on fault dipping at ~30°

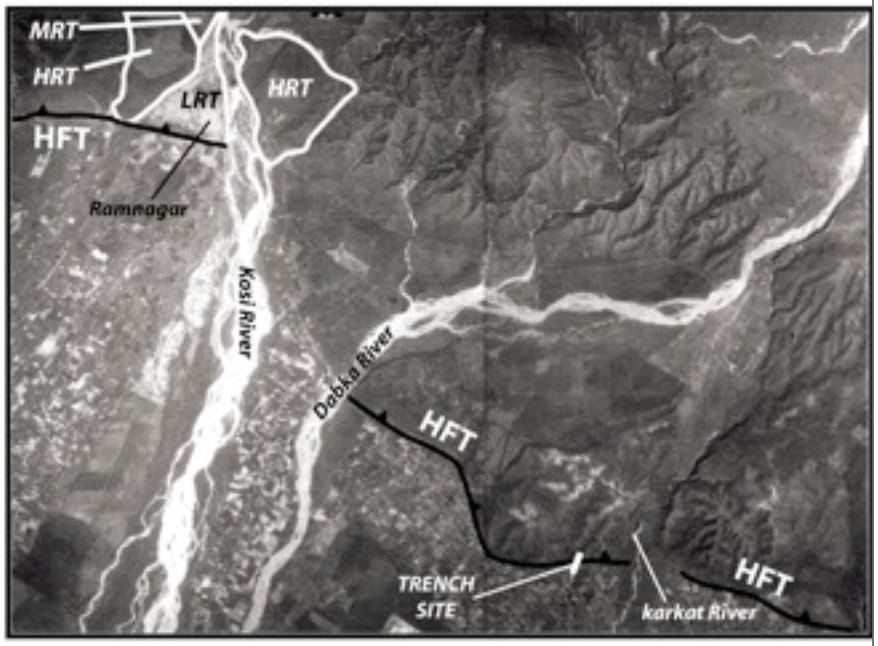


On to Site 5
Ramnagar

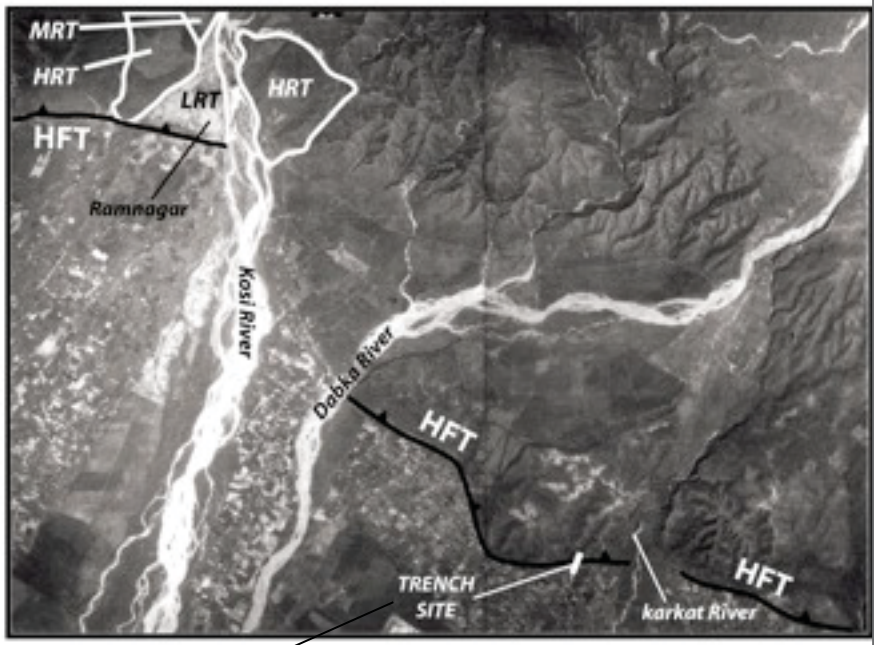


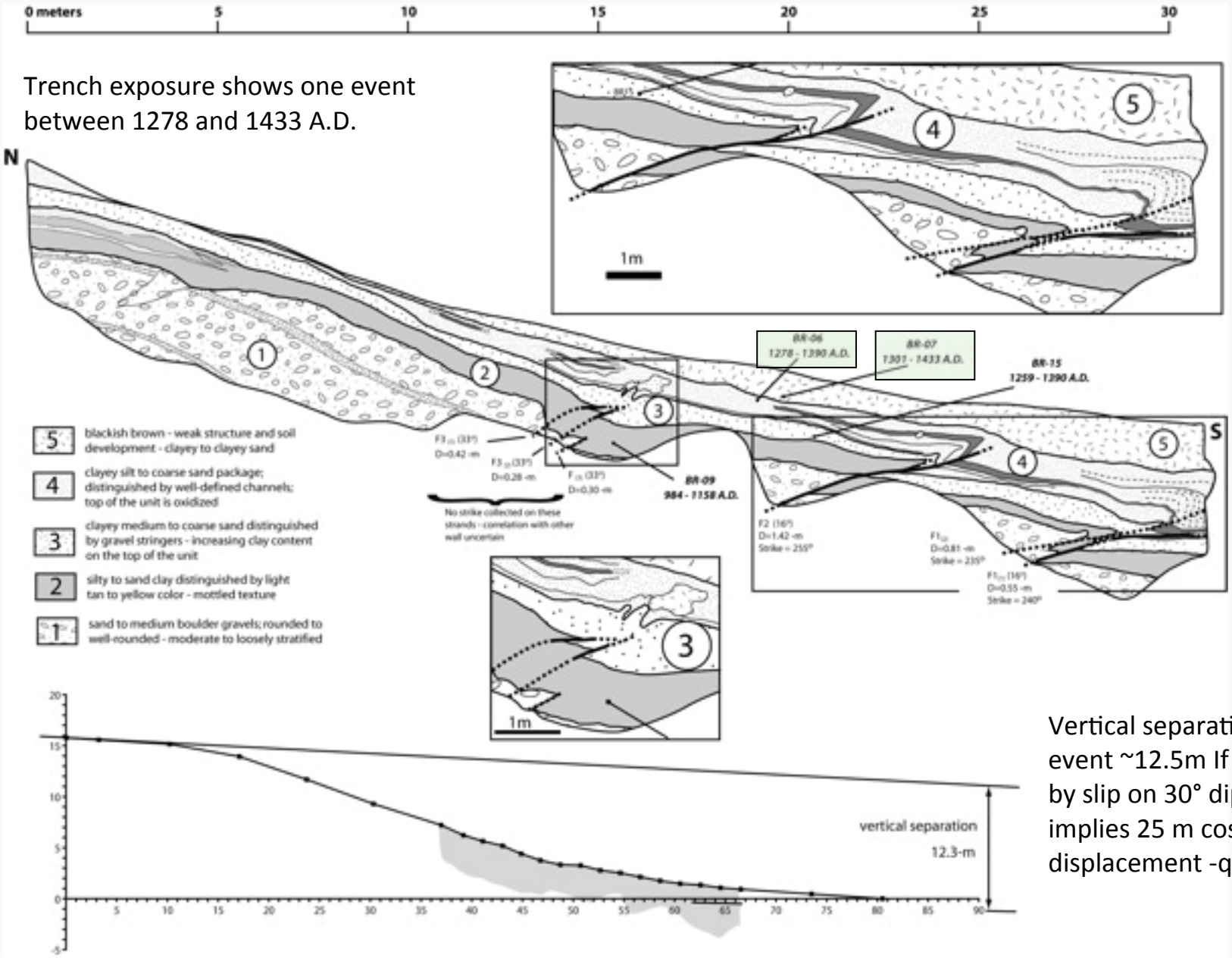
Site 6 - Ramnagar terraces of Kosi river and trench site





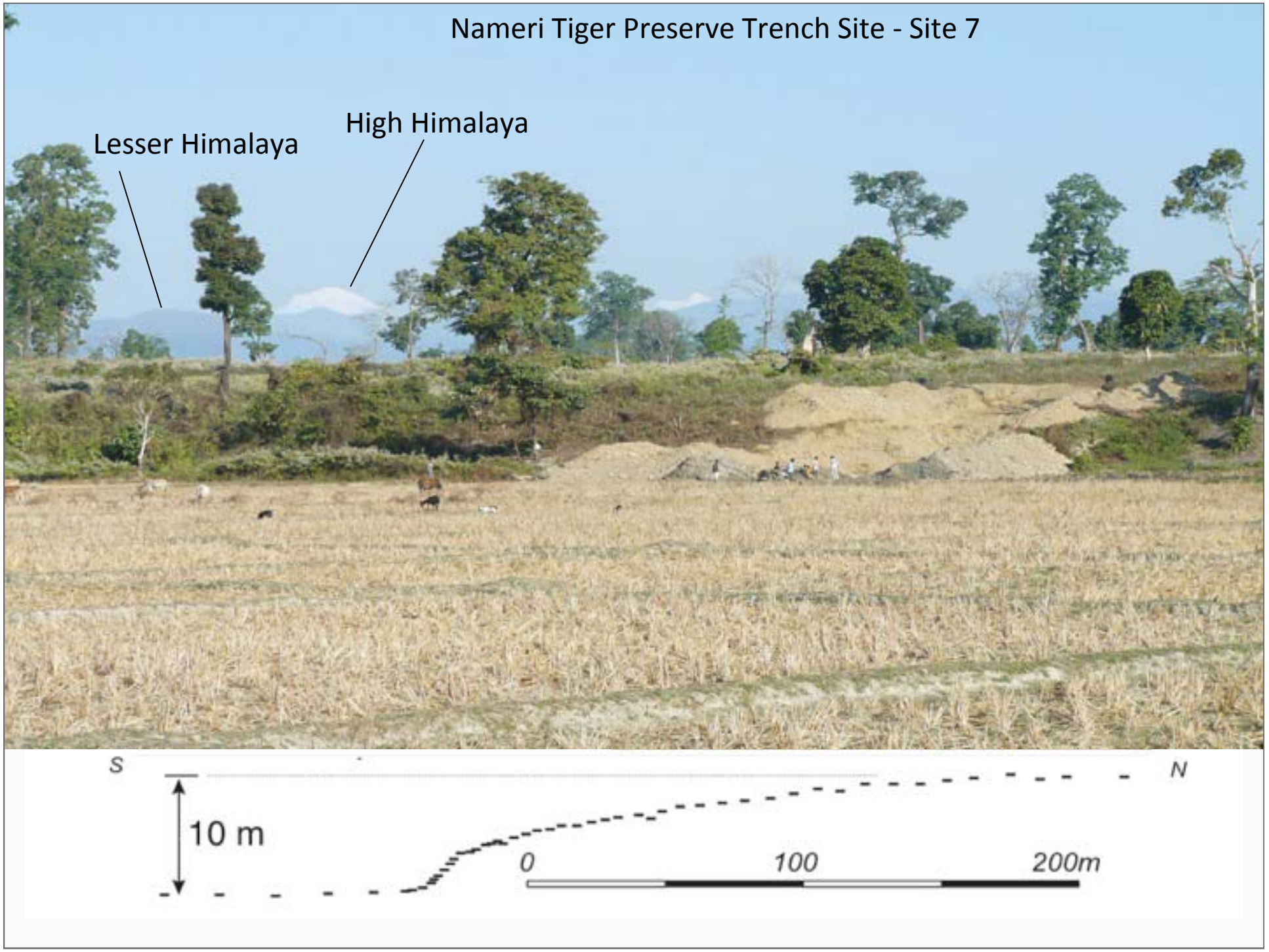
The scarp and trench…

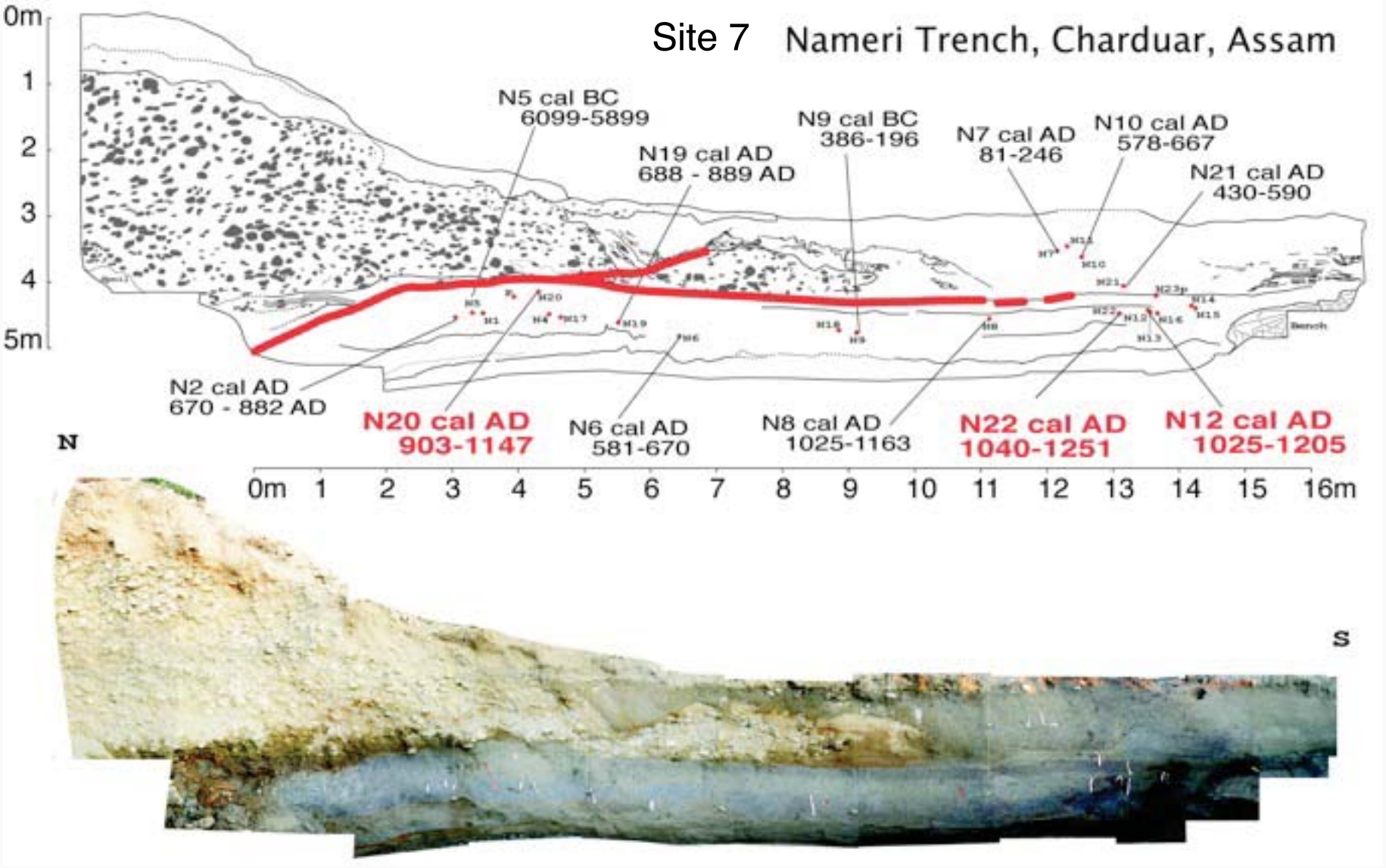




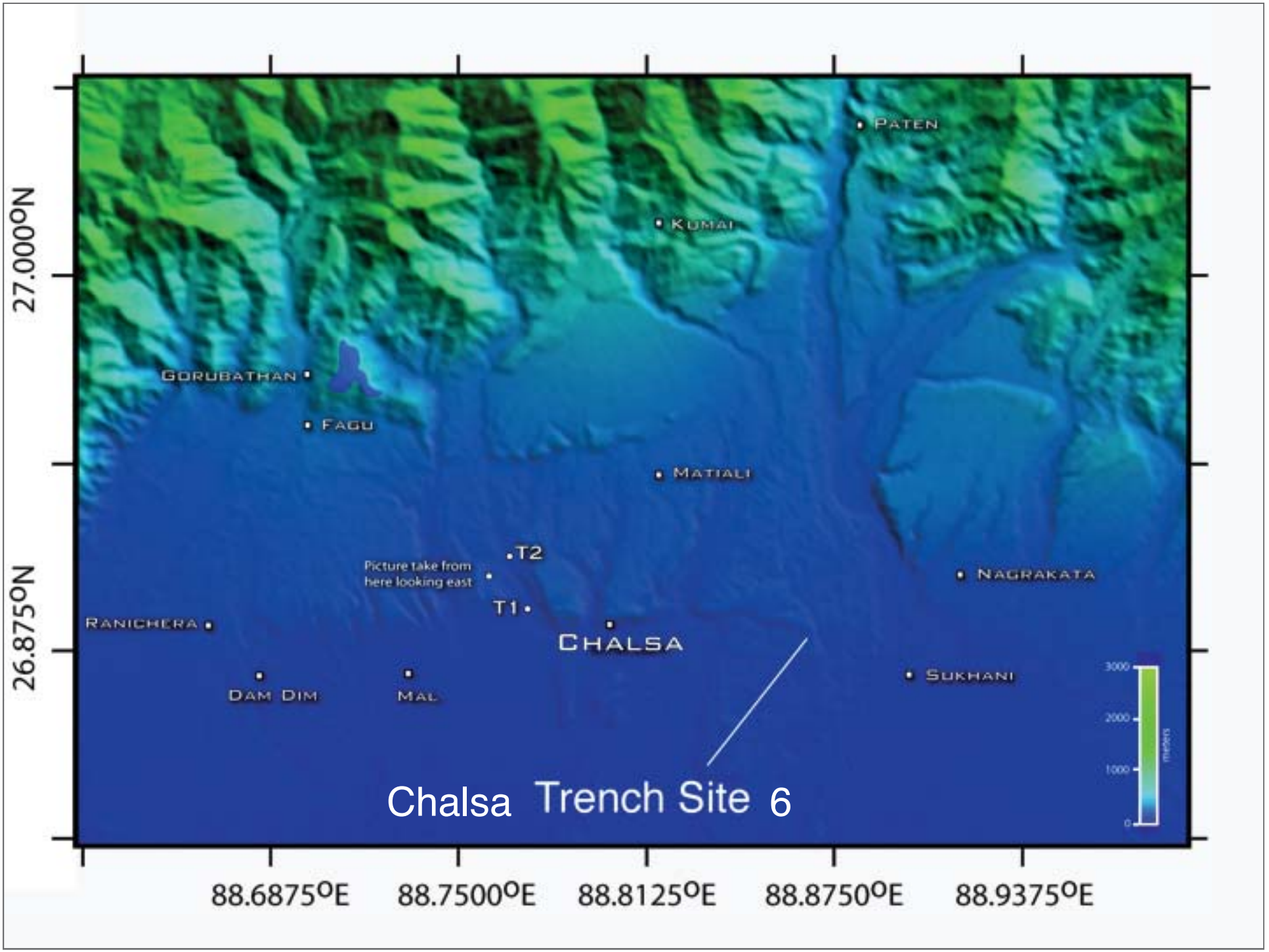
Vertical separation single event ~12.5m If accounted for by slip on 30° dipping fault - implies 25 m coseismic displacement -quite large.

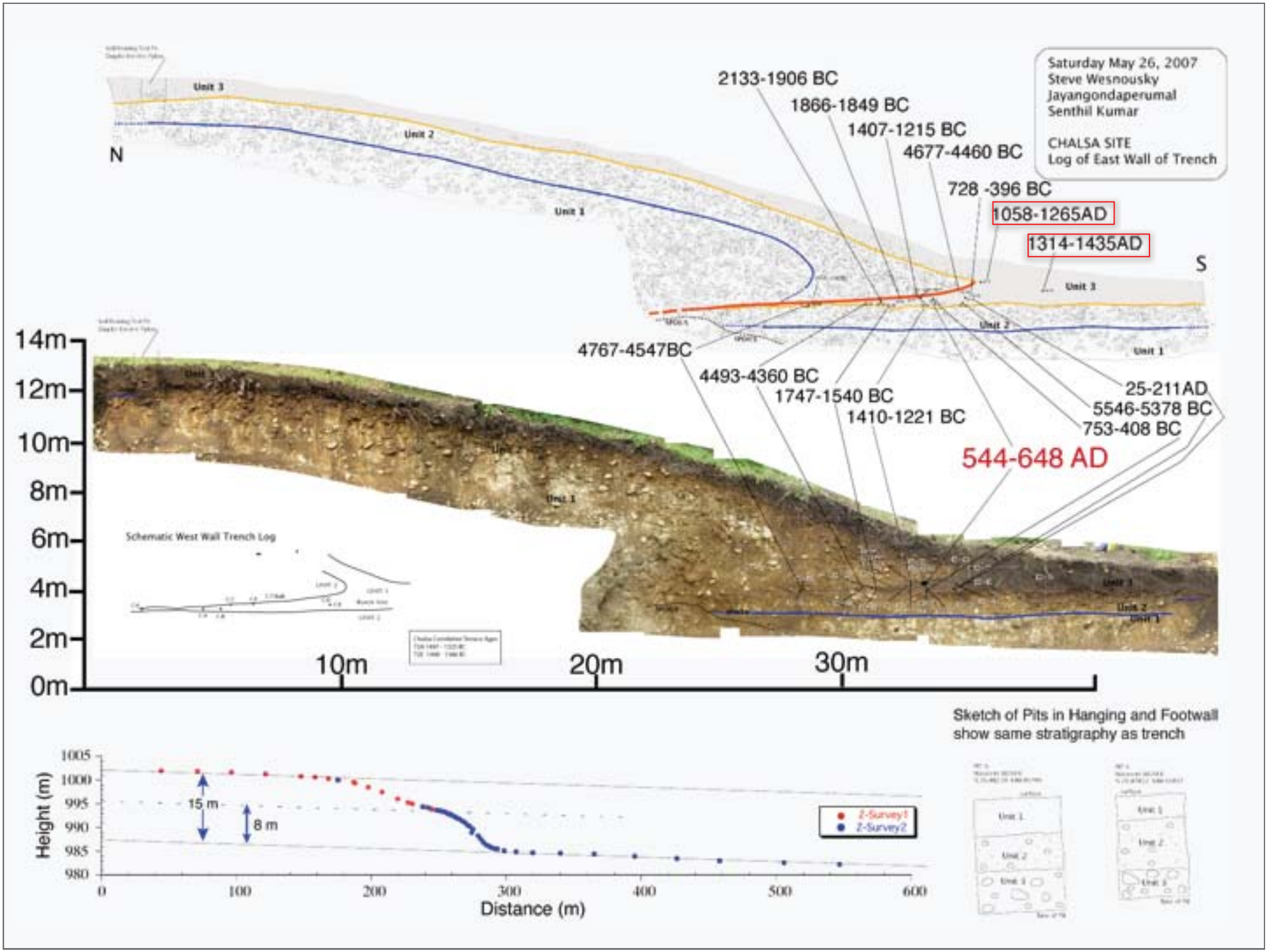
Moving east of Nepal

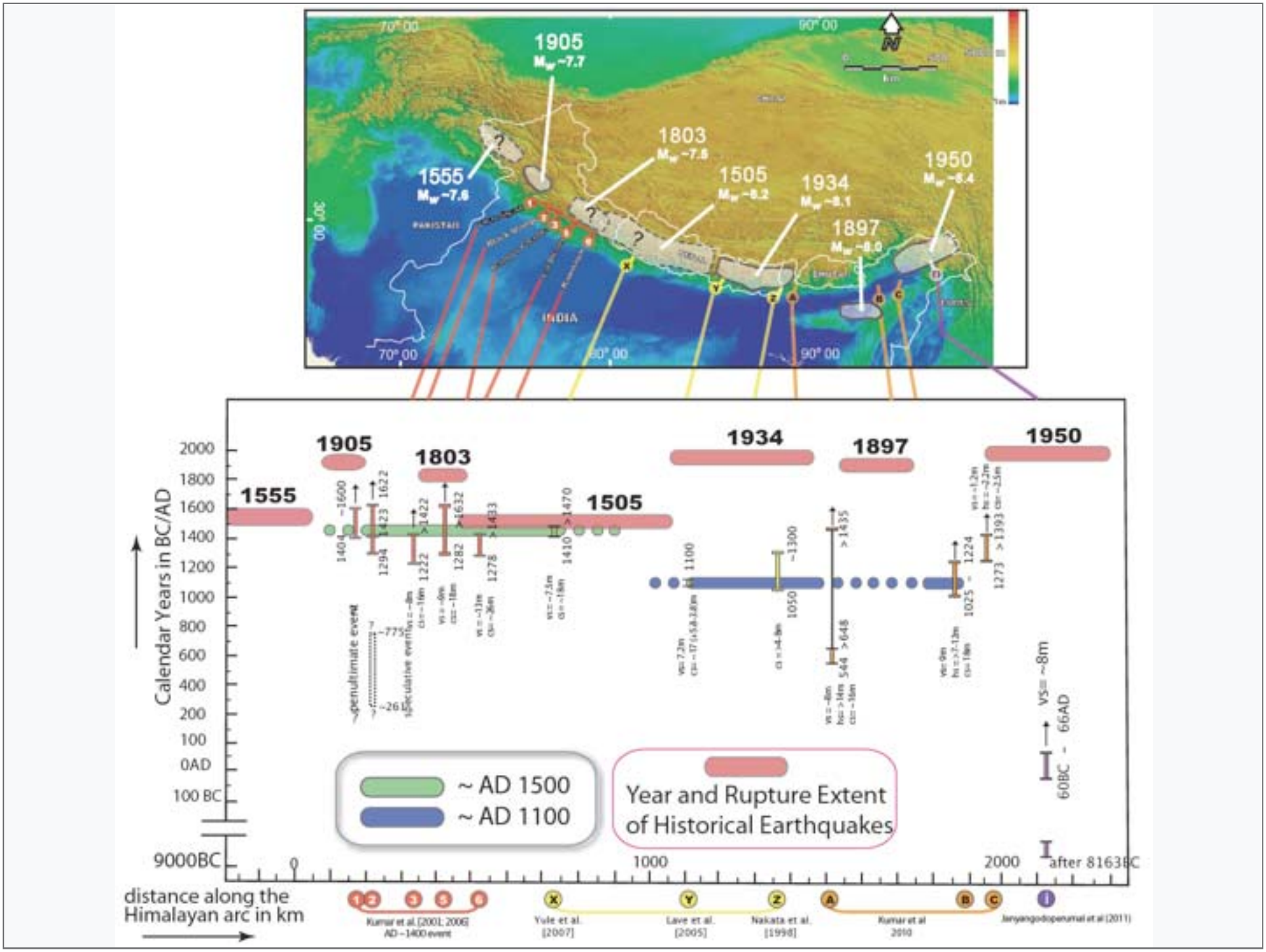

Nameri Tiger Preserve Trench Site - Site 7
Lesser Himalaya
High Himalaya
S
N
10 m
0
100
200m



~6 to 11 m horizontal shortening >=903-1147 AD
of a pre-existing scarp…


PATEN
KUMAI
GORUBATHAN
FAGU
MATIALI
T2
Picture take from here looking east
T1
NAGRAKATA
RANICHERA
CHALSA
DAM DIM
MAL
SUKHANI
Chalsa Trench Site 6
27.0000°N
26.8750°N
88.6875°E
88.7500°E
88.8125°E
88.8750°E
88.9375°E
3000
2000
1000
0
meters


Saturday May 26, 2007
Steve Wesnousky
Jayangondaperumal
Senthil Kumar
CHALSA SITE
Log of East Wall of Trench
N
S
Unit 3
Unit 2
Unit 1
2133-1906 BC
1866-1849 BC
1407-1215 BC
4677-4460 BC
728 -396 BC
1058-1265AD
1314-1435AD
4767-4547BC
4493-4360 BC
1747-1540 BC
1410-1221 BC
25-211AD
5546-5378 BC
753-408 BC
544-648 AD
14m
12m
10m
8m
6m
4m
2m
0m
10m
20m
30m
Schematic West Wall Trench Log
Sketch of Pits in Hanging and Footwall show same stratigraphy as trench
Height (m)
Distance (m)
15 m
8 m
Z-Survey1
Z-Survey2


1905
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1950
M_w ~8.4
1897
M_w ~8.0
INDIA
PAKISTAN
70° 00
90° 00
30° 00
1555
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Calendar Years in BC/AD
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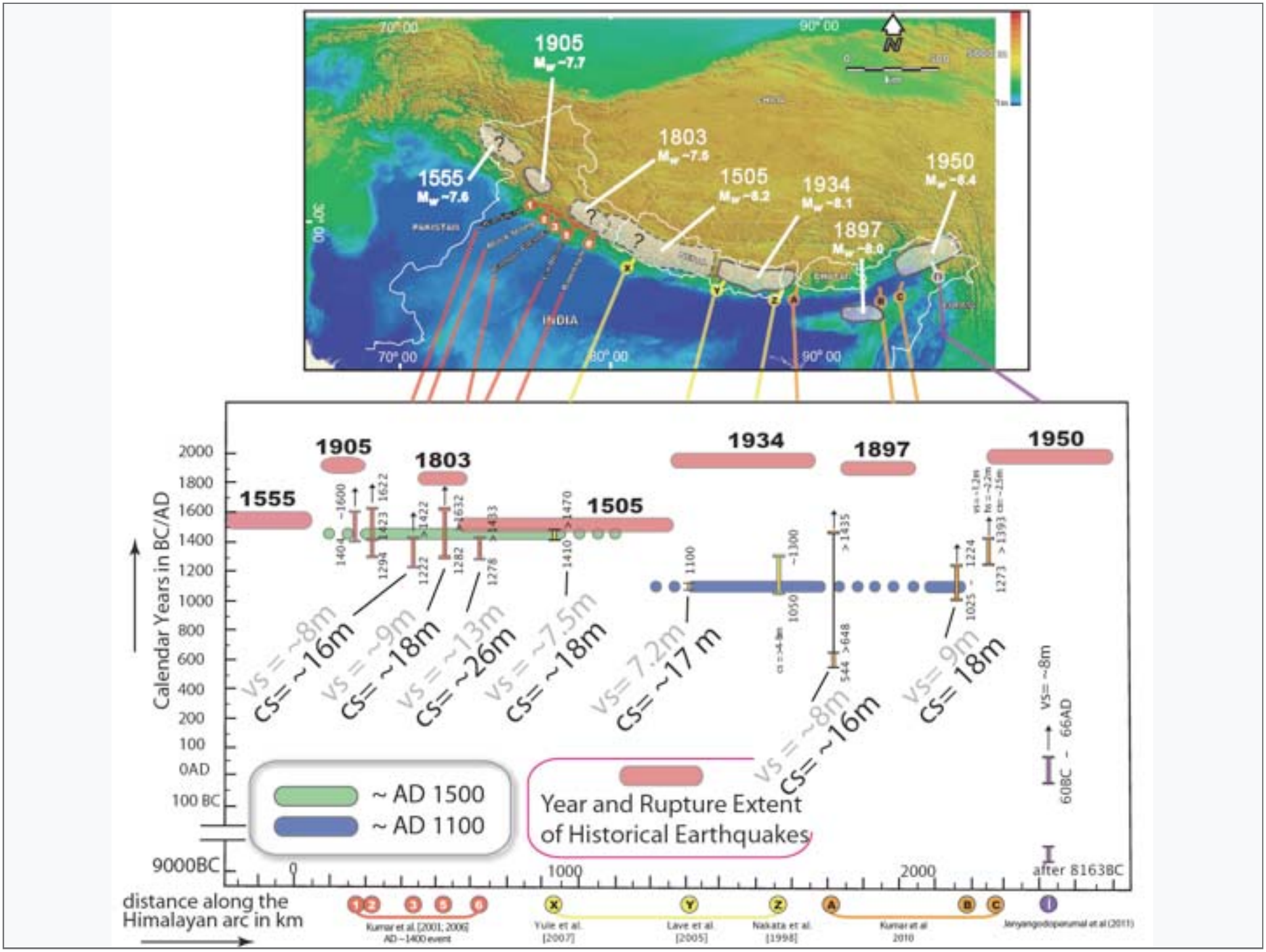
1400
1200
1000
800
600
400
200
100
0AD
100 BC
9000BC
penultimate event
speculative event
~ AD 1500
~ AD 1100
Year and Rupture Extent
of Historical Earthquakes
vs= ~8m
66AD
60BC
after 8163BC
1000
2000
distance along the
Himalayan arc in km
Kumar et al.[2001; 2006]
AD ~1400 event
Yule et al.
[2007]
Lave et al.
[2005]
Nakata et al.
[1998]
Kumar et al
2010
Jayangondaperumal et al (2011)


1905
Mw ~7.7
1803
Mw ~7.6
1555
Mw ~7.6
1505
Mw ~8.2
1934
Mw ~8.1
1950
Mw ~8.4
1897
Mw ~8.0
PAKISTAN
INDIA
70° 00
80° 00
90° 00
30° 00
1905
1803
1555
1505
1934
1897
1950
Calendar Years in BC/AD
2000
1800
1600
1400
1200
1000
800
600
400
200
100
0AD
100 BC
9000BC
vs = ~8m
CS= ~16m
vs = ~9m
CS= ~18m
vs = ~13m
CS= ~26m
vs = ~7.5m
CS= ~18m
vs= 7.2m
CS= ~17 m
vs = ~8m
CS= ~16m
vs= 9m
CS= 18m
vs= ~8m
608C - 66AD
after 8163BC
~ AD 1500
~ AD 1100
Year and Rupture Extent
of Historical Earthquakes
0
1000
2000
distance along the
Himalayan arc in km
Kumar et al. [2001; 2006]
AD ~1400 event
Yule et al.
[2007]
Lave et al.
[2005]
Nakata et al.
[1998]
Kumar et al
2010
Jayangondaperumal et al (2011)

Potential for life-loss is perhaps unsurpassed - with a population that has tripled since the last large event in 1950… the potential for an earthquake the size of the recent Sumatran earthquake or greater seems real….