Neotectonic character of Son-Narmada geo-fracture and its implication on SCR earthquakes in central India: A geomorphic and InSAR approach.

Srijan Srivastava[1], Dipanjan Bhattacharjee[2], and Anupam Chattopadhyay[3]

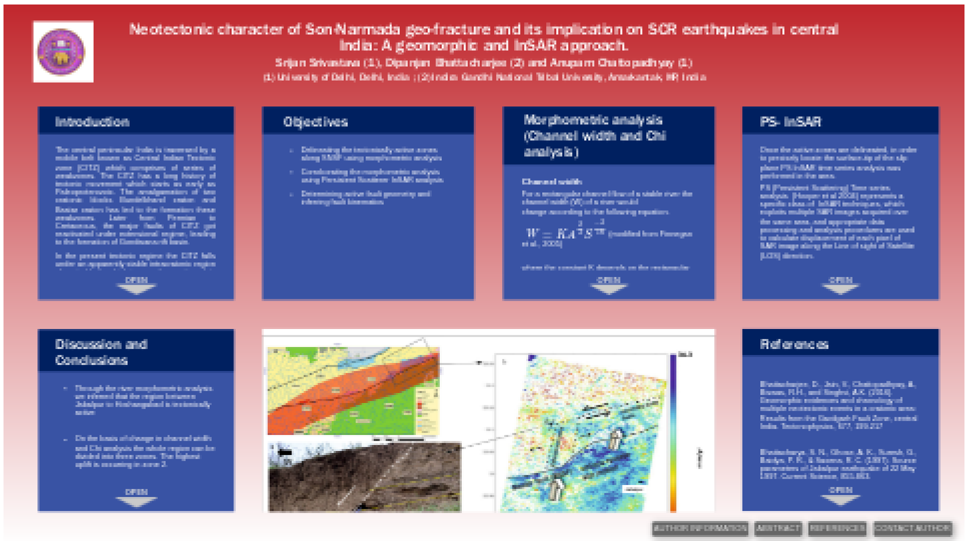
[1]University of Delhi,University of Delhi
[2]Indira Gandhi National Tribal University
[3]University of Delhi

November 26, 2022

Abstract

Apparently stable central Indian craton has been experiencing a number of micro-seismicity in and around the pristine Son-Narmada-South fault (SNSF), possibly because of creep along some reactivated or unidentified fracture planes. Drainage network being highly susceptible to even subtle active tectonics, a reconnaissance study of the area has been carried out using river morphometric analysis. Thereafter, a Principal Scattering Interferometry time series (PSInSAR-TS) analysis (Hooper et al 2004, 2007) was performed to precisely locate the surface-tip of the slip plane. And finally, the fracture geometry and orientation of the slip vector was enumerated by integrating PSINSAR with morphometric analysis. Generally, drainages respond to block uplift with abrupt incision and thereby making a very narrow channel width. However, delineating such incision from the standard Width-Depth ratio from DEM based studies becomes difficult, because of its coarser resolution. Therefore, considering rectangular channel flow for a stable river, the expected width was compared with the actual width of the river measured from high resolution Sentinel II images following the relation modified after Finnegan et al., 2005; which states that W =KAˆ(2/3)Sˆ(-3/16), where the constant K depends on the rectangular channel geometry, manning constant and rainfall in the area, A is upper catchment area and S is slope of the river reaches. A NE-SW trending zone of narrower channel width was identified with this procedure which was interpreted as a result of block uplift, later confirmed from the rate of uplift preliminarily calculated using an expression derived from basic stream-power equation: U=K(((Z(a)-Z(o))/X)ˆn)(Aˆm), where the uplift (U) is a function of erodibility (K), river catchment area (A) and chi (χ) value as per Perron and Royden 2012. PSInSAR-TS analysis of the area delineated an average net-slip rate of 11mm/year along a number of NE-SW trending south dipping oblique slip reverse faults, with sinistral strike slip components, arranged in enechelon pattern and are softly linked to each other with jogs accommodating movements in normal sense. Lastly, the fault geometry was confirmed by comparing the deformation map generated from the InSAR technique with the field evidence and previous studies.

Neotectonic character of Son-Narmada geo-fracture and its implication on SCR earthquakes in central India: A geomorphic and InSAR approach.



Srijan Srivastava (1), Dipanjan Bhattacharjee (2) and Anupam Chattopadhyay (1)

(1) University of Delhi, Delhi, India ; (2) Indira Gandhi National Tribal University, Amarkantak, MP, India

PRESENTED AT:

INTRODUCTION

The central peninsular India is traversed by a mobile belt known as Central Indian Tectonic zone (CITZ) which comprises of series of weakzones. The CITZ has a long history of tectonic movement which starts as early as Paleoproterozoic during the amalgamation of two cratonic blocks Bundelkhand craton and Bastar craton. Later from Permian to Cretaceous, the major faults of CITZ got reactivated under an extension regime, leading to the formation of Gondwana rift basin. In the present tectonic regime the CITZ falls under apparently stable intracratonic region of central India which is away from active plate boundary, but still a number of seismic activity has occurred in the area leading to a number of micro and major earthquakes, such as 1927 Son Valley earthquake (M 6.5), 1938 Satpura Earthquake (Mb 6.2), 1997 Jabalpur earthquake (Mb 6.0) to name a few (Figure 1). Geomorphic studies along Gavilgarh and Tapti fault (Figure 2) shows signature of reactivation with an oblique reverse slip motion along the faults in the current stress conditions (Bhattacharjee et al., 2016, Copley et al., 2014) indicating that the resurgence along the pre-existing geofractures in the region could be responsible for these earthquakes.

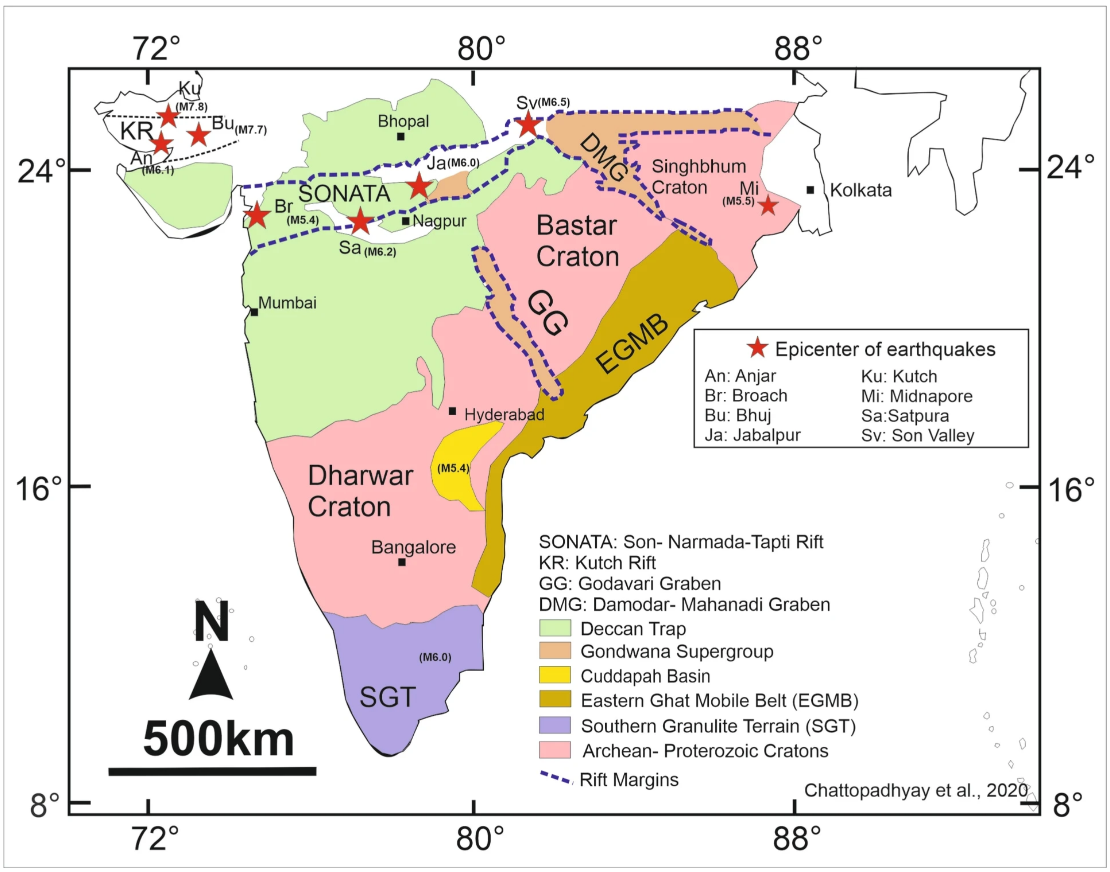
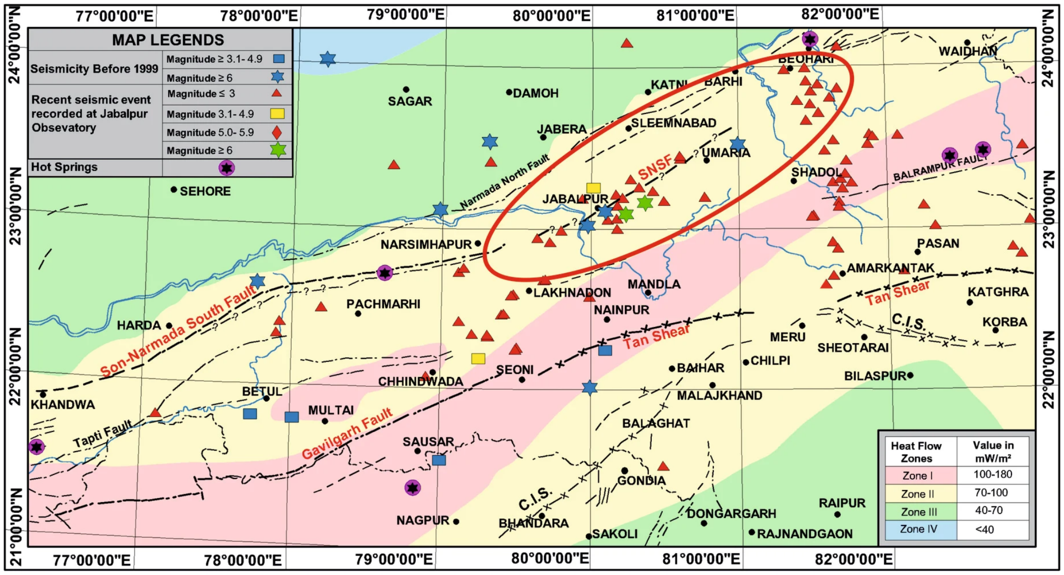


Figure 1. Recent and historical earthquakes in central India (Chattopadhyay et al., 2020)



Chattopadhyay et al., 2020

Figure 2. Major paleo Geofractures traversing central India and their association with earthquakes within the region. The red ellipse defines our study area. (Chattopadhyay et al., 2020)

It is observed that most of the recent earthquakes in the region is concentrated along Precambrian Son Narmada South Fault (SNSF) (Figure 2), thus the study of the fault characteristics of the SNSF in the present stress regime is of utmost importance. Most neotectonic studies related to SNSF is done using geophysical techniques and earthquake studies confined to certain reaches of fault making it difficult to examine the overall characteristic of the fault. In order to study the holistic behavior of SNSF, in the present work we will investigate the neotectonic stability along a stretch of SNSF from Jabalpur to Hoshangabad using river morphometric analysis and enumerate the geometry and kinematics of the fault using a novel approach of integrating morphometric analysis along with Persistent Scatterer Interferometry technique.

OBJECTIVES

- Delineating the tectonically active zones along SNSF using morphometric analysis
- Corroborating the morphometric analysis using Persistent Scatterer InSAR analysis
- Determining active fault geometry and inferring fault kinematics

MORPHOMETRIC ANALYSIS (CHANNEL WIDTH AND CHI ANALYSIS)

Channel width

For a rectangular channel flow of a stable river the channel width (W) of a river would change according to the following equation.

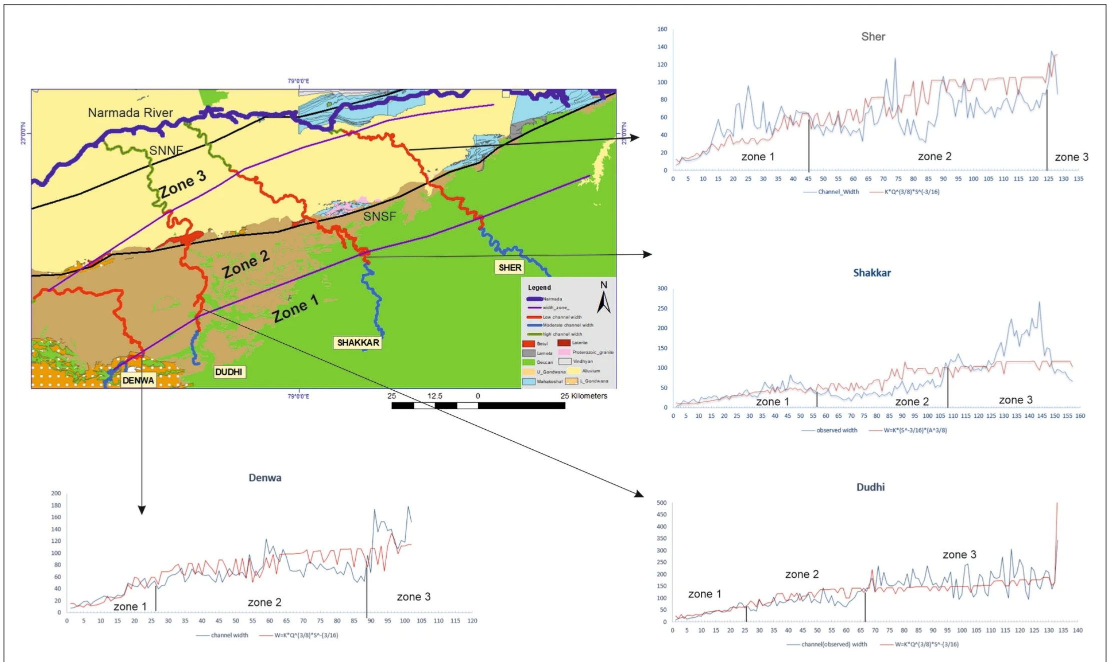
$$W = KA^{\frac{2}{3}}S^{\frac{-3}{16}} \text{ (modified from Finnegan et al., 2005)}$$

where the constant K depends on the rectangular channel geometry, manning constant and rainfall in the area, A is upper catchment area and S is slope of the river reaches.

- In the present study we focused on quantifying the variation of channel width within a particular reach of the river flowing over uniform base material and compared it with the expected river width (W) of the river in case of steady-state flow.

- Drainages respond to block uplift with an abrupt incision and thereby making a very narrow channel width, thus a zone showing active uplift will have a lower actual channel width compare to expected river width (W).

Results:



Channel width analysis: The actual channel width is lower than calculated width in the central zone (zone2) indicating possible uplift

Figure 3. Channel width analysis of tributaries of Narmada. In the graph the blue curve indicate actualchannel width and the red curve indicate calculated channel width. Rivers showing highest incision incentral zone indicating uplift.

- Four tributaries of Narmada (Sher, Shakkar, Denwa and Dudhi) having similar stream order and drainage area were selected for the analysis (Figure 3).
- Initially the actual channel width of the river were similar to calculated channel width, moving downstream the actual channel width decreased with respect to calculated channel width and moving further north there was an increase in actual channel width with respect to calculated width.
- The whole region can be divided into three zones on the basis of this variation of channel width. (Figure 3)
- The river is showing high incision within central zone which might be attributed to differential uplift within this zone.

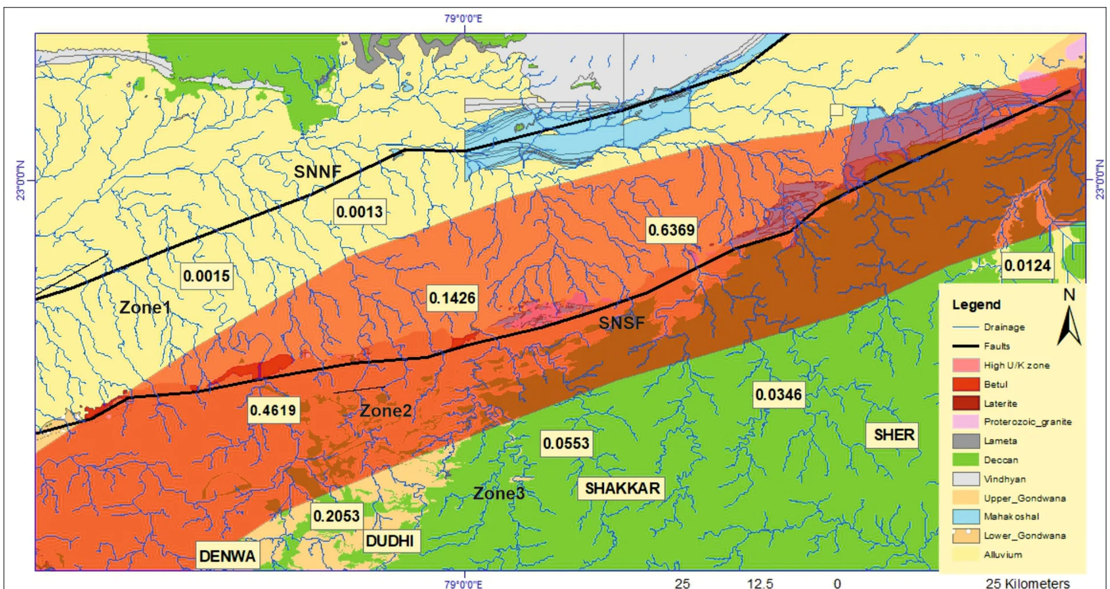
Chi analysis

Through the previous analysis we inferred a spatial changes in rock uplift and on the basis of that divided the area into 3 zones. In order to get a better understanding we calculated the rate of uplift within each zone using a modified form of basic stream power equation (Perron & Raydon, 2012) given in equation below

$$U = K((\frac{z_x - z_o}{\chi})^n)A_o^m$$

Where, ‘z’ is elevation, ‘U’ is the rate of rock uplift relative to a reference elevation, ‘K’ is an erodibility coefficient, ‘A’ is drainage area, and m and n are constants (concavity index)

Results:



Average U/K value of three zones delineated by channel width analysis

Figure 4. The average U/K value for each zone. The central zone although being dominated by less resistive rocks shows higher U/K value indicating influence of tectonics

- Using chi analysis, it is observed that the central region (Zone 2) shows a higher U/K value compare to the Zone 1 and Zone 3 which indicate either an uplift or low erodibility in central region (Figure 4).
- Since the central zone is dominated by highly erodible Gondwana sandstones the major factor contributing to high U/K is tectonics.

Through the morphometric analysis we can infer the central block is showing an uplift.

PS- INSAR

Once the active zones are delineated, in order to precisely locate the surface-tip of the slip plane PS InSAR time series analysis was performed in the area.

PS (Persistent Scattering) Time series analysis (Hooper et al 2004) represents a specific class of InSAR techniques, which exploits multiple SAR images acquired over the same area, and appropriate data processing and analysis procedures are used to calculate displacement of each pixel of SAR image along the Line of sight of Satellite (LOS) direction.

Results:

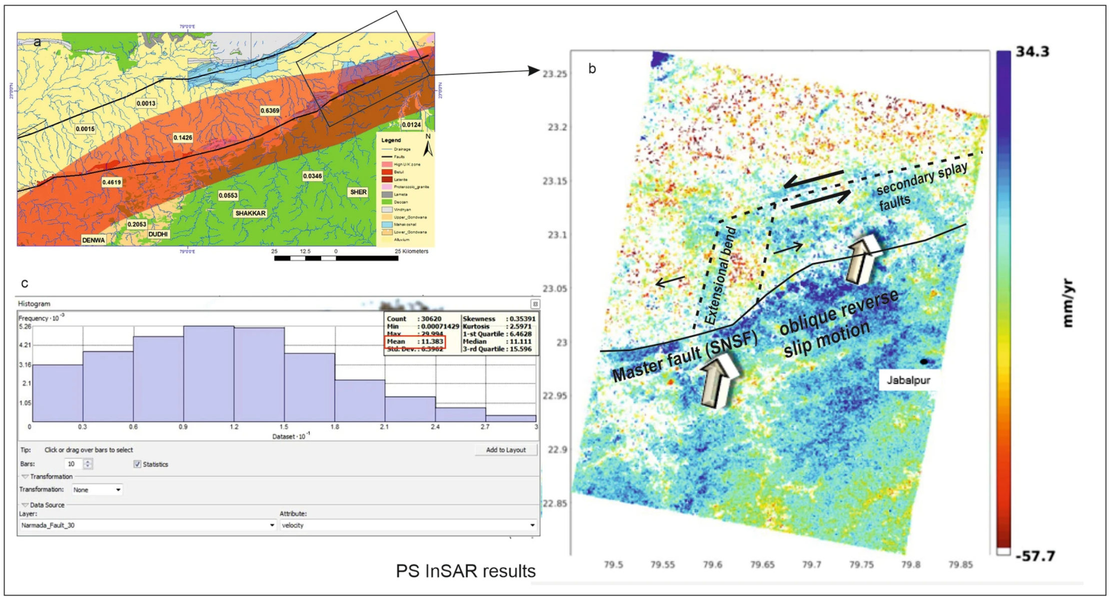
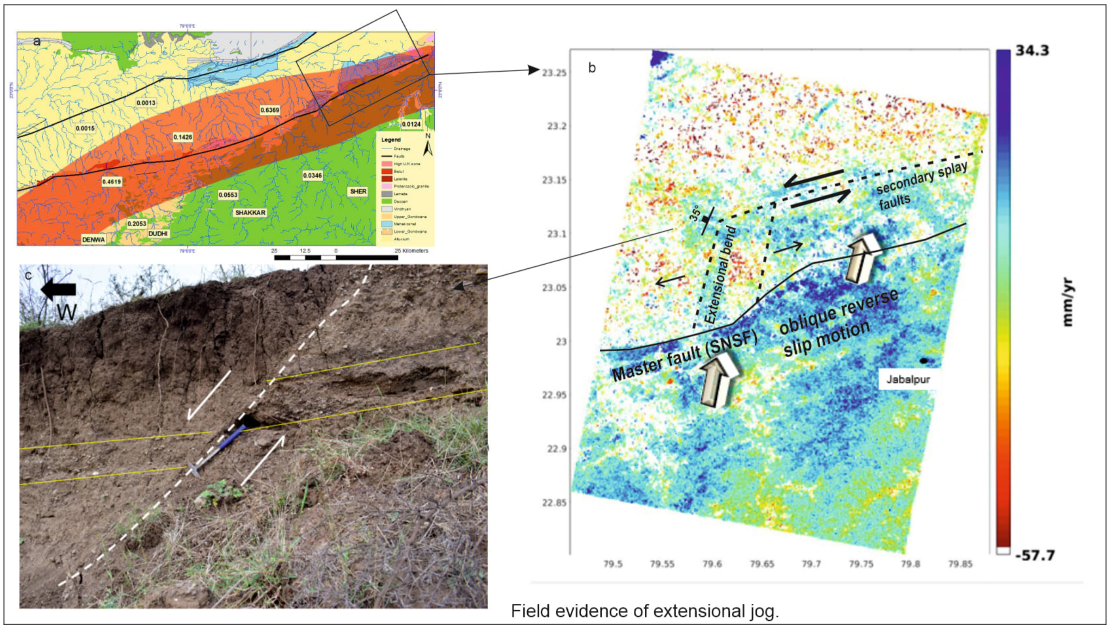


Figure 5. PS InSAR results. (a)Through morphometric analysis the area demarcates a zone of uplift. (b) Deformation map generated through our analysis using PS InSAR, an enechalon fault is inferred, where master faults shows an oblique reverse slip. (c) Mean LOS velocity along NE- SW trending faults

After the analysis two prominent NE-SW trending PS clusters were observed showing a movement towards the Line Of Sight (LOS) of the satellite near the Narmada and Bagaspur area.

- The mean velocity of the two clusters are 11.38 mm/yr towards the LOS respectively
- The two clusters are connected with a NNE trending soft jog giving an impression of an en echelon type fault.
- We can infer that the motion along the major NE-SW trending fault shows either a reverse nature with southern block as footwall or a strike slip nature with a sinistral strike slip sense or a combination of both.

Integrating morphometric analysis along with PS InSAR we infer intraplate stress in the central India is accommodated by a slow rate motion along ENE –WSW trending geofractures. The motion along the master geofractures is of oblique reverse slip nature with a sinistral strike slip component leading to formation of dilational jog along the left lateral bend (Figure 5).



Field evidence of extensional jog.

Figure 6. PS InSAR velocity map (mm/yr) indicates NE-SW trending faults connected by a dialational jog. The dilational jog is observed in the field, in form of normal fault within Alluvium deposit.

The evidence of the dilational jog is observed in the field in the form of a normal fault, (Figure 6). The fault was observed within the channel sediment indicating a recent deformation and the attitude of the fault is 210/35° NW.

DISCUSSION AND CONCLUSIONS

- Through the river morphometric analysis we inferred that the region between Jabalpur to Hoshangabad is tectonically active
- On the basis of change in channel width and Chi analysis the whole region can be divided into three zones. The highest uplift is occurring in zone 2.
- Using morphometric analysis along with PSInSAR analysis performed near Jabalpur region we inferred that the present intraplate stress in the central India is accommodated by a slow rate motion along NE–SW trending geofractures. The motion along the master geofractures is of oblique reverse slip nature with a sinistral strike slip component leading to formation of dilational jog along the left lateral bend. A similar fault structure is inferred by Mandal 2015 after studying the source mechanism of multiple earthquakes (M_L > 3) in this region (Figure 7). This provides a validation to our analysis.
- The motion of the fault inferred from PS-InSAR analysis also matches with the focal plane solution of 1997 Jabalpur earthquake (Bhattacharya et al., 1997).

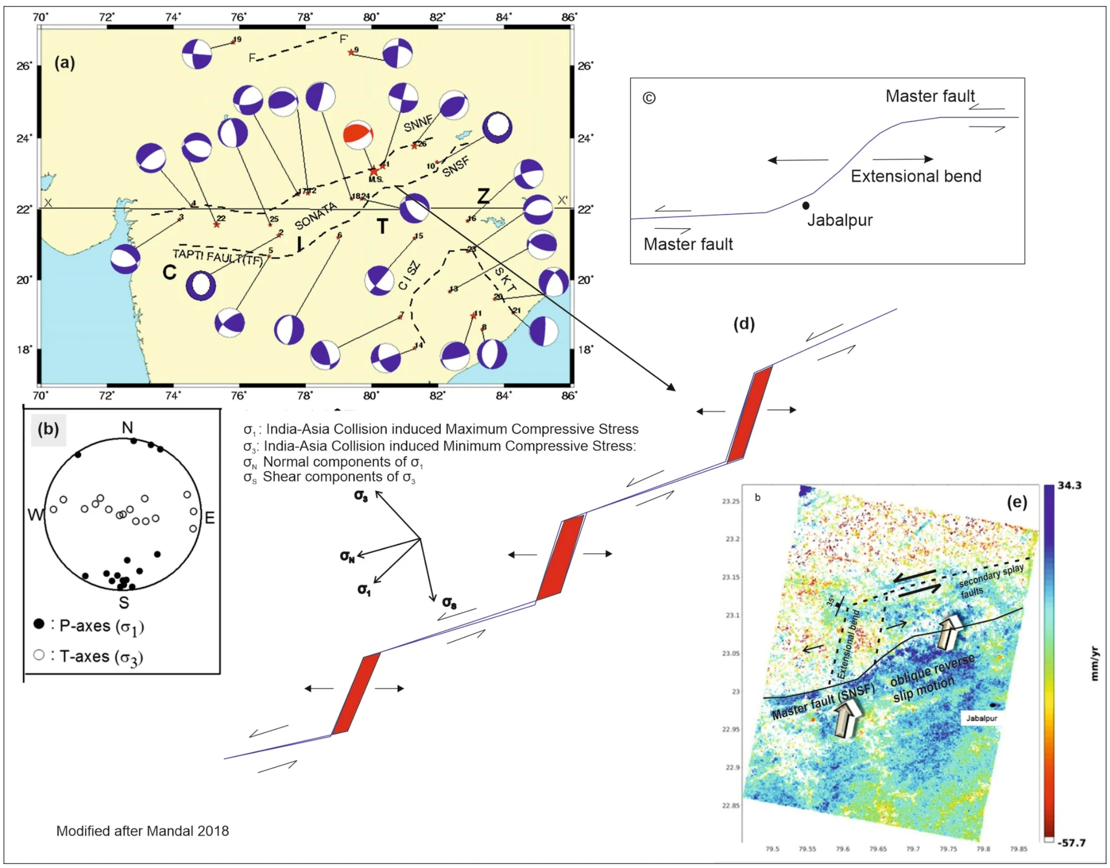
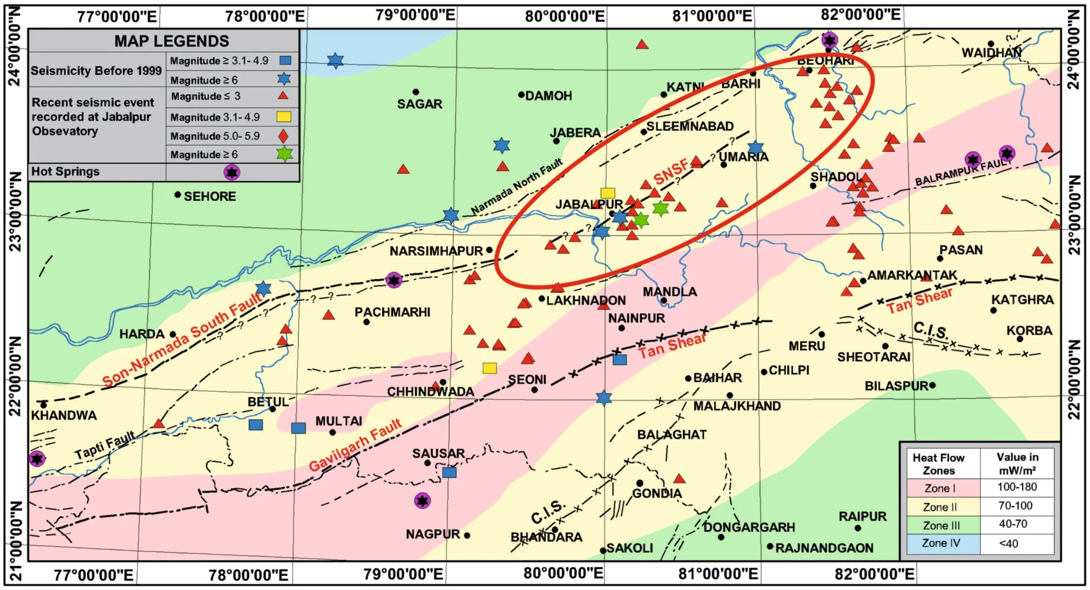
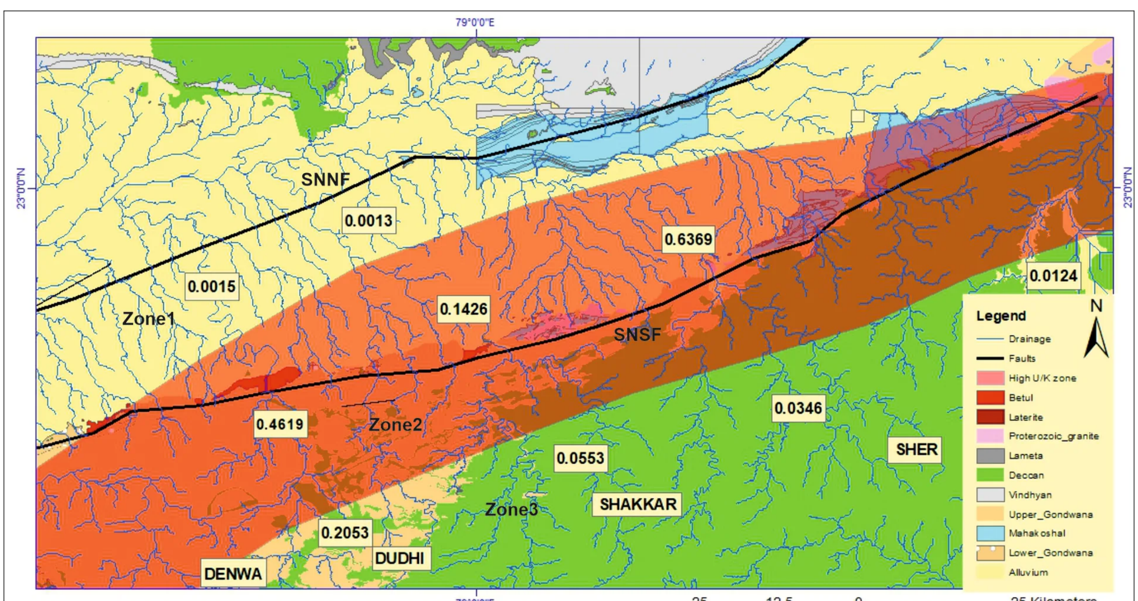


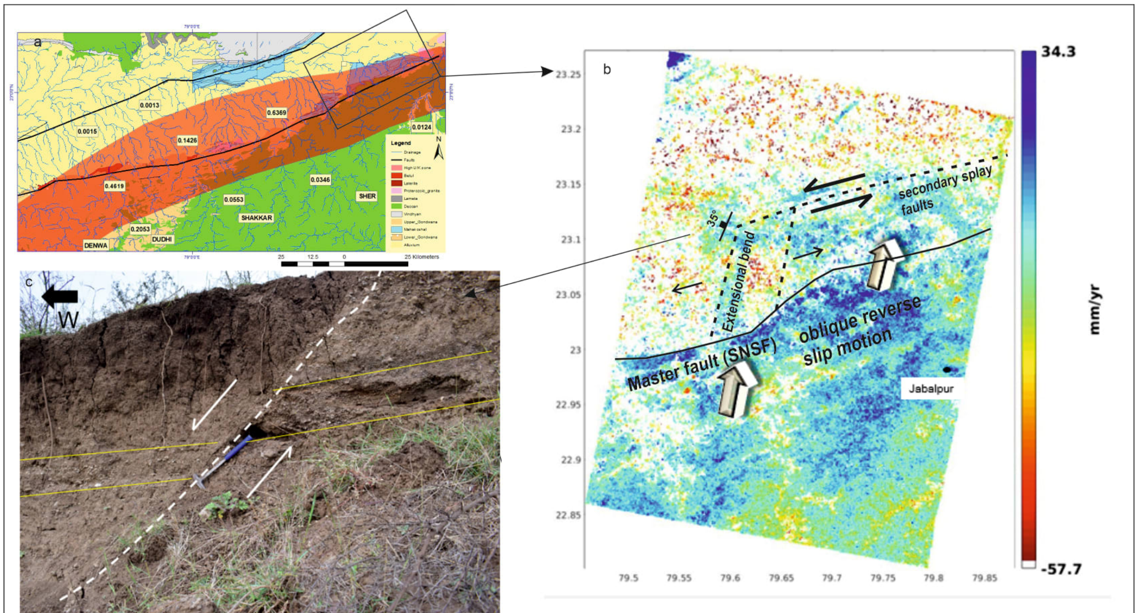
Figure 7. Comparing our inference of fault geometry and kinematics from PS InSAR with previous studies in the area. (a) Fault plane solution of earthquakes (M >3) around SNSF performed by Mandal 2018. (b) Lower hemisphere equal area projection of P- and T-axes for 16 historical earthquakes of Mw >5.0 (Modified after Mandal 2018) (c) Generalized regional structure of SNSF (after Mohanty 2011) (d) Details of ambient stress and associated transpression and transtension zones developed along the sinistral bend shown in figure(c) (modified after Mandal 2018). (e) Fault geometry and kinematics inferred from PS InSAR analysis.



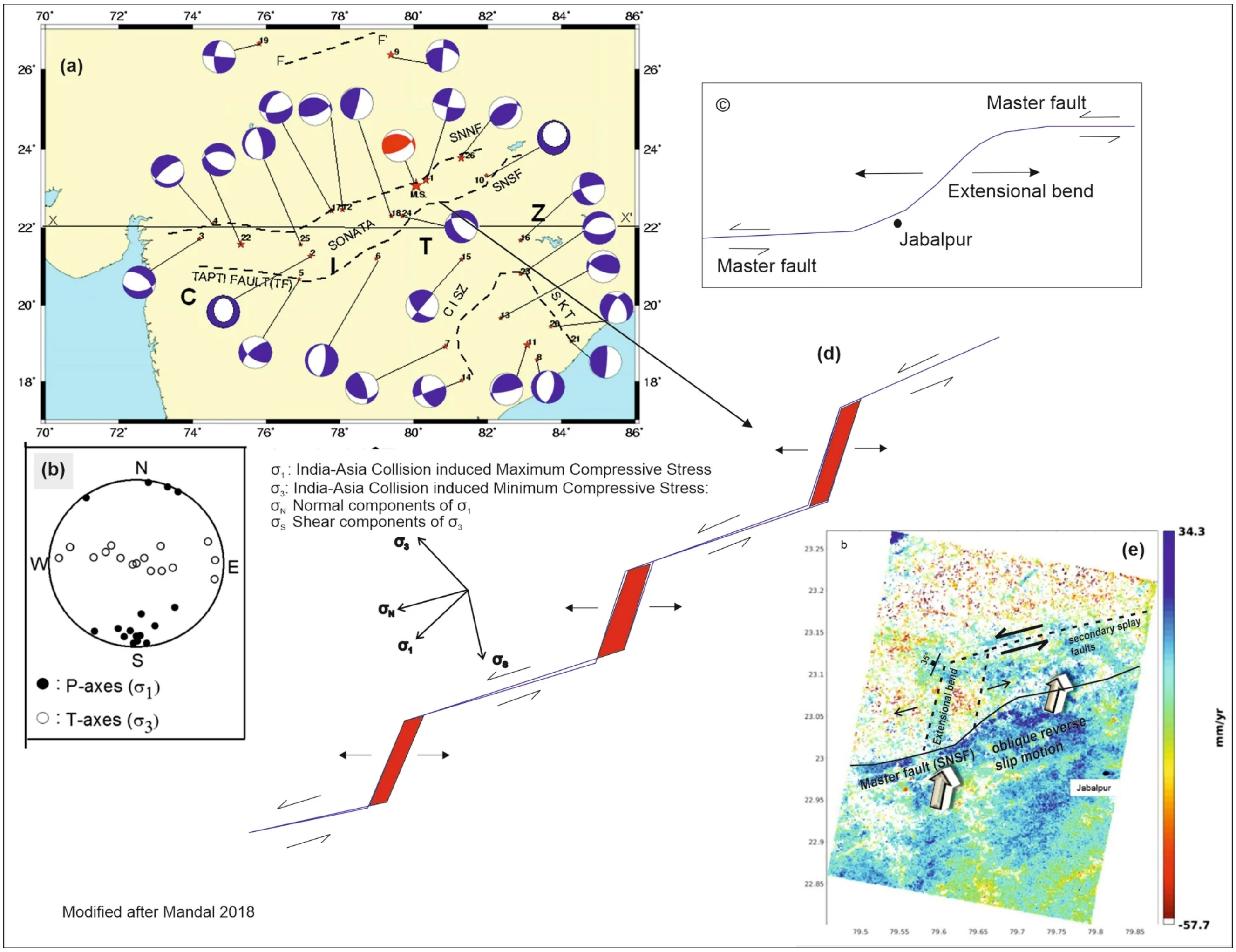
Chattopadhyay et al., 2020

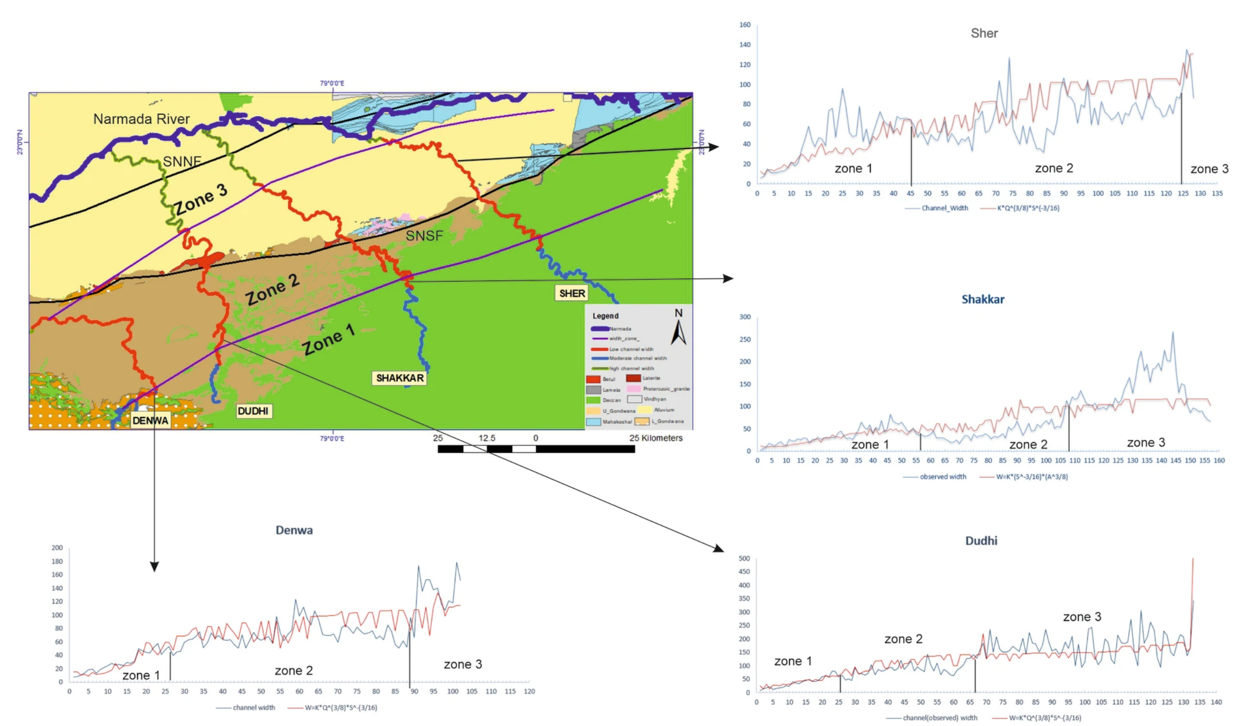


Average U/K value of three zones delineated by channel width analysis



Field evidence of extensional jog.


(a)
SONATA
TAPTI FAULT(TF)
SNNF
SNSF
C I SZ
S K T
C
T
Z
(b)
N
S
W
E
● : P-axes (σ_1)
○ : T-axes (σ_3)
©
Master fault
Extensional bend
Jabalpur
Master fault
(d)
σ_1 : India-Asia Collision induced Maximum Compressive Stress
σ_3: India-Asia Collision induced Minimum Compressive Stress:
σ_N Normal components of σ_1
σ_S Shear components of σ_3
(e)
secondary splay faults
Extensional bend
Master fault (SNSF)
oblique reverse slip motion
Jabalpur
34.3
-57.7
mm/yr
Modified after Mandal 2018



Channel width analysis: The actual channel width is lower than calculated width in the central zone (zone2) indicating possible uplift

AUTHOR INFORMATION

Srijan Srivastava

Research Scholar

Department of Geology

University of Delhi

Delhi, India

Dr, Dipanjan Bhattacharjee

Assistant Professor

Department of Geology

Indira Gandhi National Tribal University

Amarkantak, M.P, India

Prof. Anupam Chattopadhyay

Professor, H.O.D

Department of Geology

University of Delhi

Delhi, India.

ABSTRACT

Apparently stable central Indian craton has been experiencing a number of micro-seismicity in and around the pristine Son-Narmada-South fault (SNSF), possibly because of creep along some reactivated or unidentified fracture planes. Drainage network being highly susceptible to even subtle active tectonics, a reconnaissance study of the area has been carried out using river morphometric analysis. Thereafter, a Principal Scattering Interferometry time series (PSInSAR-TS) analysis (Hooper et al 2004, 2007) was performed to precisely locate the surface-tip of the slip plane. And finally, the fracture geometry and orientation of the slip vector was enumerated by integrating PSINSAR with morphometric analysis.

Generally, drainages respond to block uplift with abrupt incision and thereby making a very narrow channel width. However, delineating such incision from the standard Width-Depth ratio from DEM based studies becomes difficult, because of its coarser resolution. Therefore, considering rectangular channel flow for a stable river, the expected width was compared with the actual width of the river measured from high resolution Sentinel II images following the relation modified after Finnegan et

al., 2005; which states that $W = KA^{(2/3)} S^{(-3/16)}$, where the constant K depends on the rectangular channel geometry, manning constant and rainfall in the area, A is upper catchment area and S is slope of the river reaches. A NE-SW trending zone of narrower channel width was identified with this procedure which was interpreted as a result of block uplift, later confirmed from

the rate of uplift preliminarily calculated using an expression derived from basic stream-power equation: $U= K((z_x-z_b/\chi)^n)A_o^m$,

where the uplift (U) is a function of erodibility (K), river catchment area and chi (χ) value as per Perron and Royden 2012. PSInSAR-TS analysis of the area delineated an average net-slip rate of 11mm/year along a number of NE-SW trending south dipping oblique slip reverse faults, with sinistral strike slip components, arranged in enechelon pattern and are softly linked to each other with jogs accommodating movements in normal sense. Lastly, the fault geometry was confirmed by comparing the deformation map generated from the InSAR technique with the field evidence and previous studies.

REFERENCES

Bhattacharjee, D., Jain, V., Chattopadhyay, A., Biswas, R.H., and Singhvi, A.K. (2016). Geomorphic evidences and chronology of multiple neotectonic events in a cratonic area: Results from the Gavilgarh Fault Zone, central India. Tectonophysics, 677, 199-217

Bhattacharya, S. N., Ghose, A. K., Suresh, G., Baidya, P. R., & Saxena, R. C. (1997). Source parameters of Jabalpur earthquake of 22 May 1997. Current Science, 855-863.

Chattopadhyay, A., Bhattacharjee, D., & Srivastava, S. (2020). Neotectonic fault movement and intraplate seismicity in the central Indian shield: A review and reappraisal. Journal of Mineralogical and Petrological Sciences, 190824b

Copley, A., Mitra, S., Sloan, R. A., Gaonkar, S., & Reynolds, K. (2014). Active faulting in apparently stable peninsular India: Rift inversion and a Holocene-age great earthquake on the Tapti Fault. Journal of Geophysical Research: Solid Earth, 119(8), 6650-6666.

Finnegan, N. J., Roe, G., Montgomery, D. R., & Hallet, B. (2005). Controls on the channel width of rivers: Implications for modeling fluvial incision of bedrock. Geology, 33(3), 229-232.

Hooper, A., Zebker, H., Segall, P., & Kampes, B. (2004). A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. Geophysical research letters, 31(23).

Mandal, H. S. (2018). Earthquake dynamics in the Central India Tectonic Zone. Natural hazards, 92(2), 885-905.

Mohanty, S. (2011). Crustal strain patterns in the Satpura Mountain Belt, Central India: implications for tectonics and seismicity in stable continental regions. Pure and applied geophysics, 168(5), 781-795.

Perron, J. T., & Royden, L. (2013). An integral approach to bedrock river profile analysis. Earth Surface Processes and Landforms, 38(6), 570-576