Deformation and metamorphic evolution of Chotanagpur Gneissic Complex (CGC), East Indian Shield

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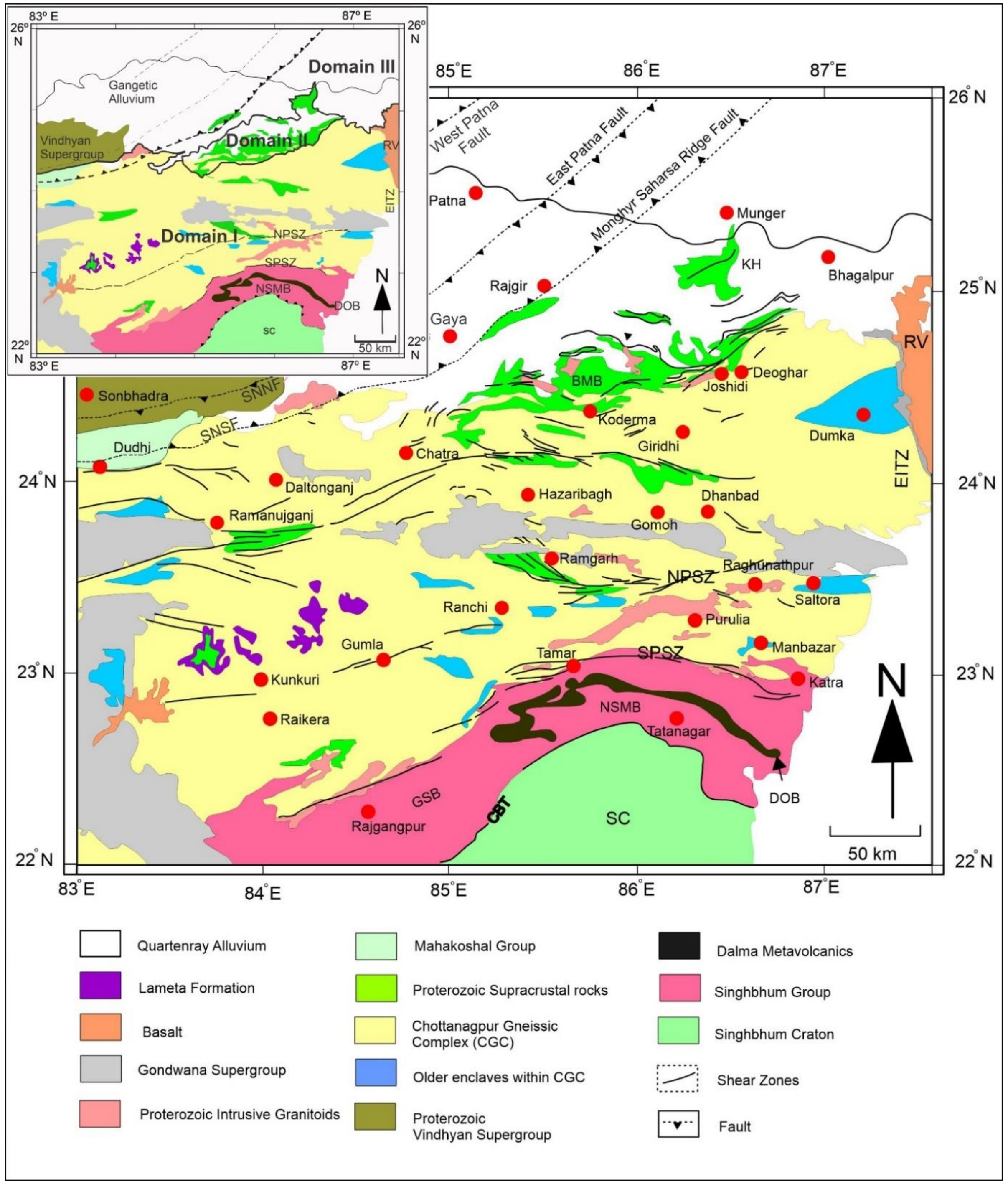
Introduction

Fig.A. Generalized geological map of the CGC showing the main locations of the available petrographic & structural data. Shear zone networks within the CGC along with the peripheral group of rocks are also shown here. SC: Singhbhum carton; CBT: Copper Belt Thrust; NSMB: North Singhbhum Mobile Belt; GSB: Gangpur Schist Belt; DOB: Dalma Ophiolite Belt; SPSZ: South Purulia Shear Zone; NPSZ: North Purulia Shear Zone; EITZ: Eastern Indian Tectonic Zone; BMB: Bihar Mica Belt; RV: Rajmahal Volcanics; KH: Kharagpur Hills; SNNF: Son Narmada North Fault; SNSF: Son Narmada South Fault (Modified after Chatterjee & Ghose, 2011; Sanyal & Sengupta, 2012; Das et al., 2020; Sequeira & Bhattacharya, 2021).



Geological map of study area

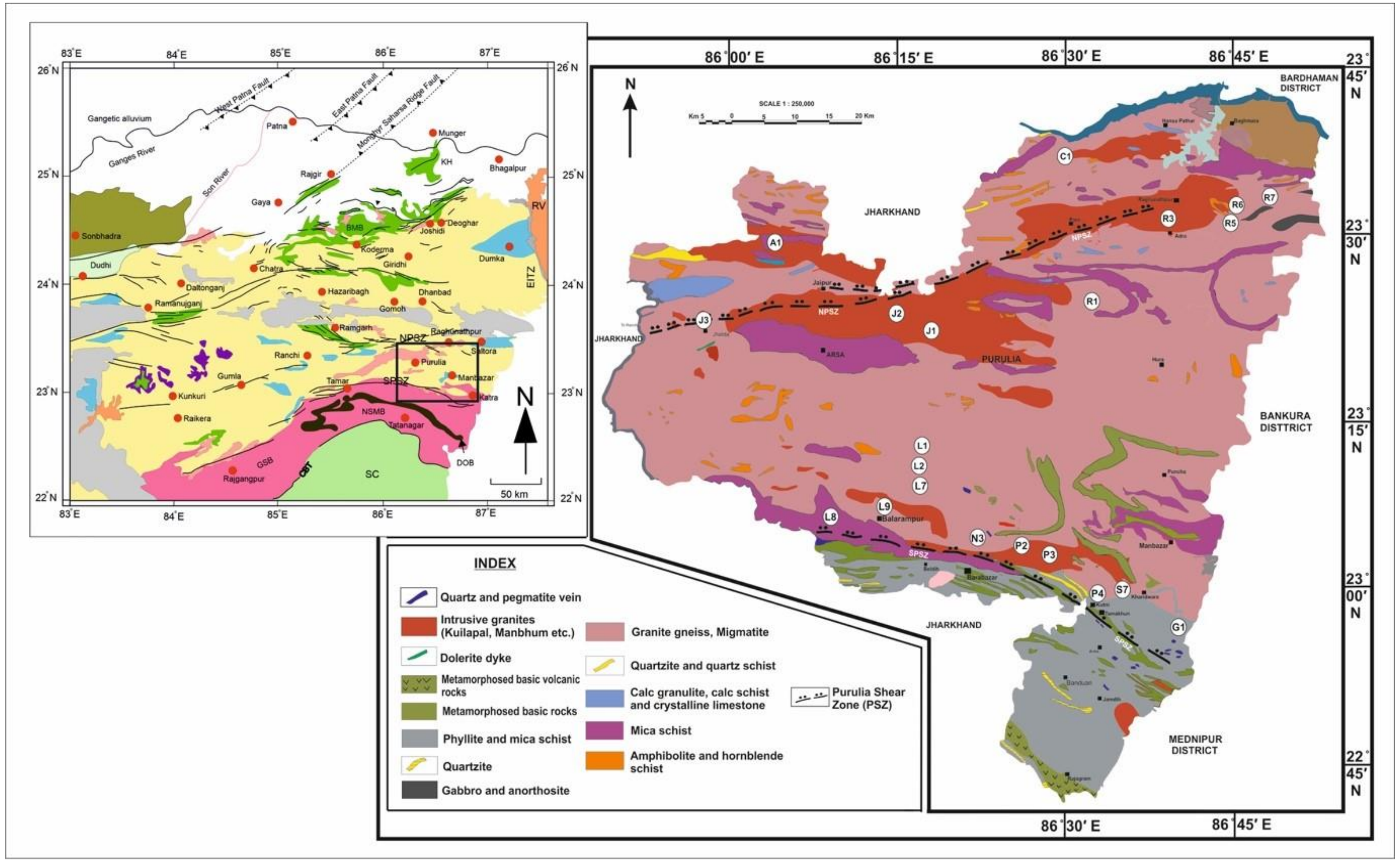


Fig. Lithological map of Purulia showing field locations around North Purulia Shear zone (NPSZ) and South Purulia Shear Zones (SPSZ) (Modified after GSI, 2001).

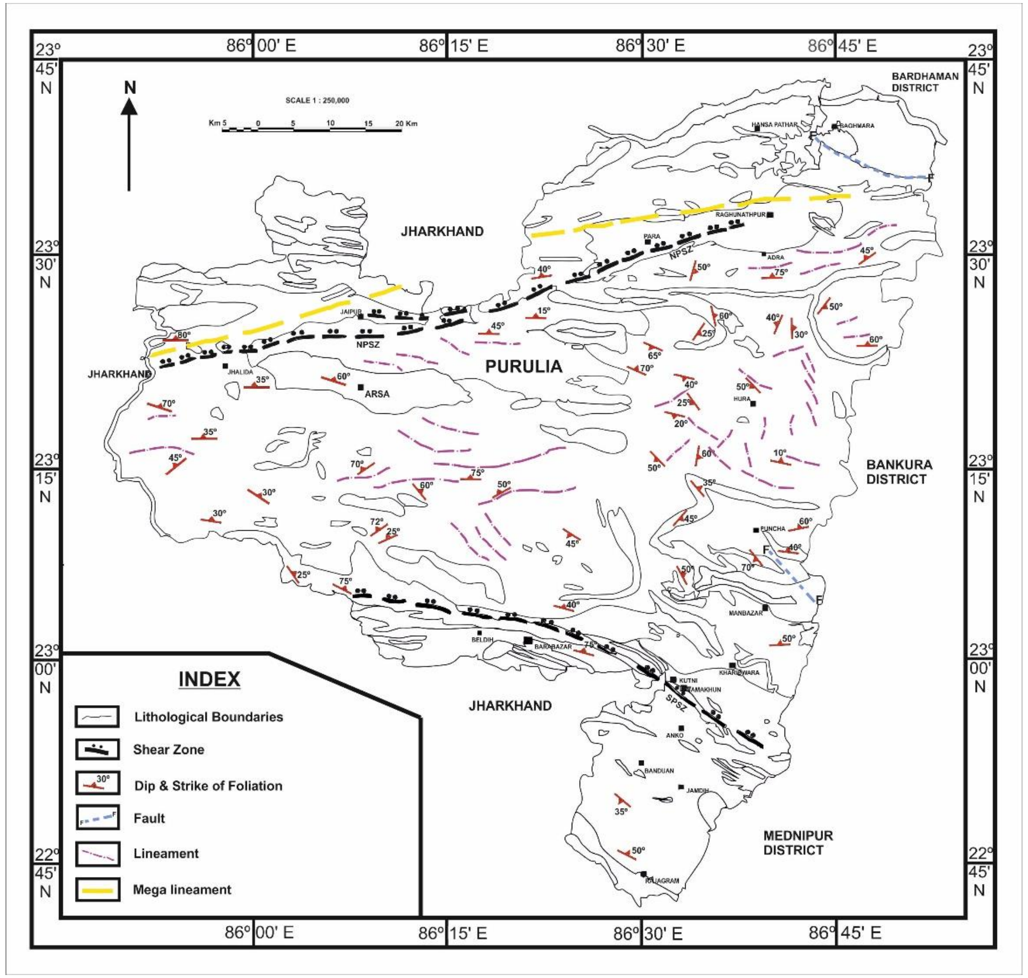


Fig. Structural map of the area showing planar and linear structures and major fault zones (Modified after GSI, 2001).

Mesoscale structures along SPSZ

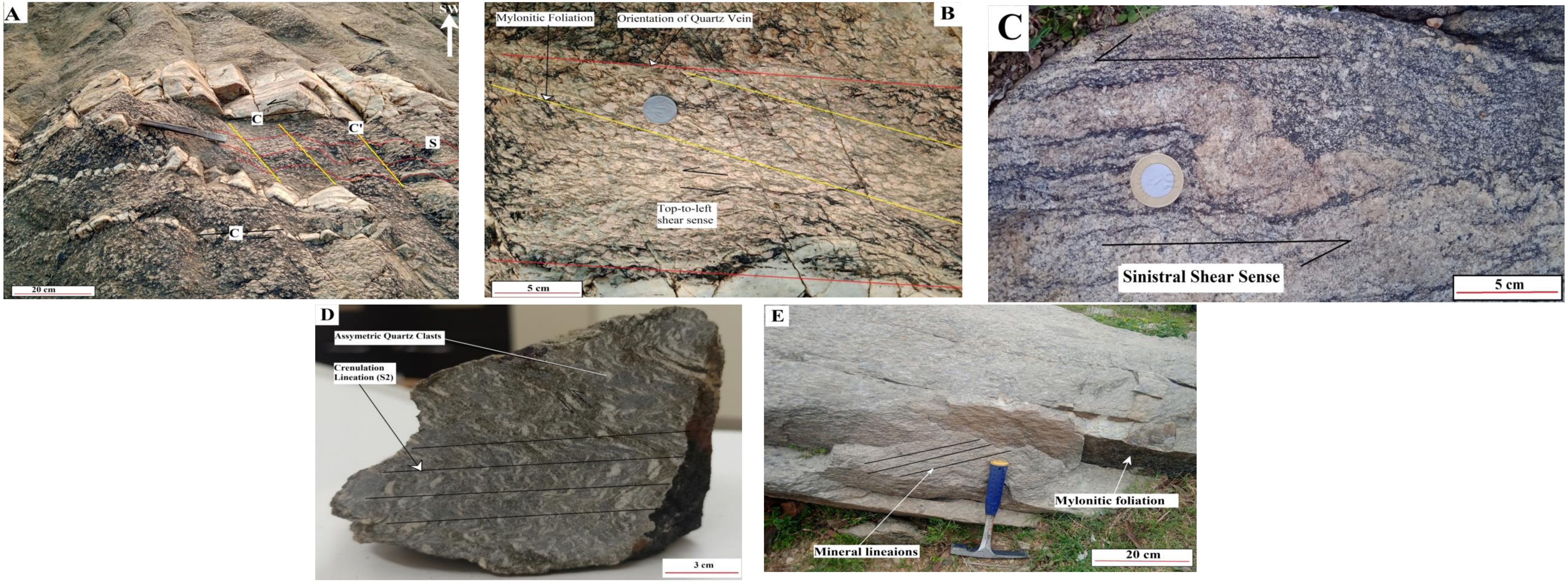
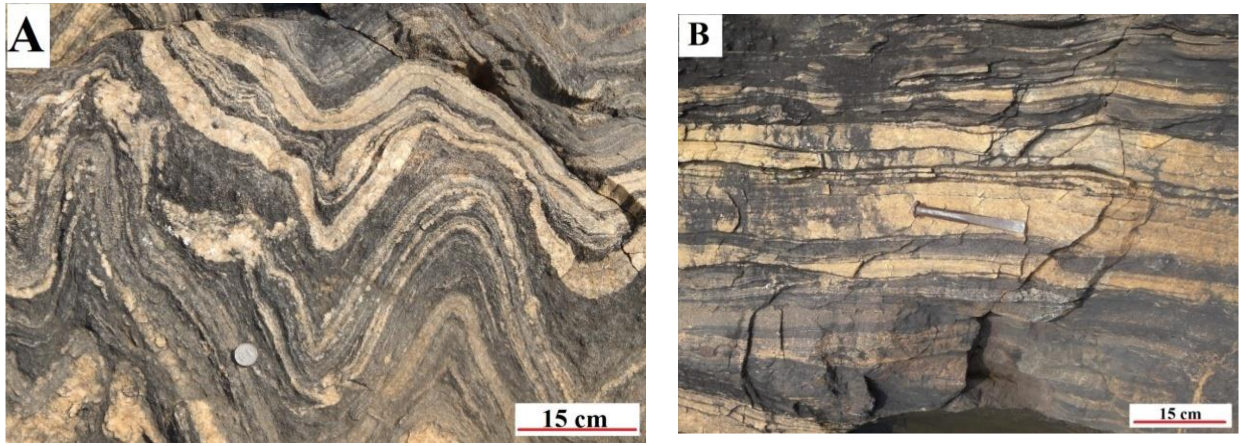
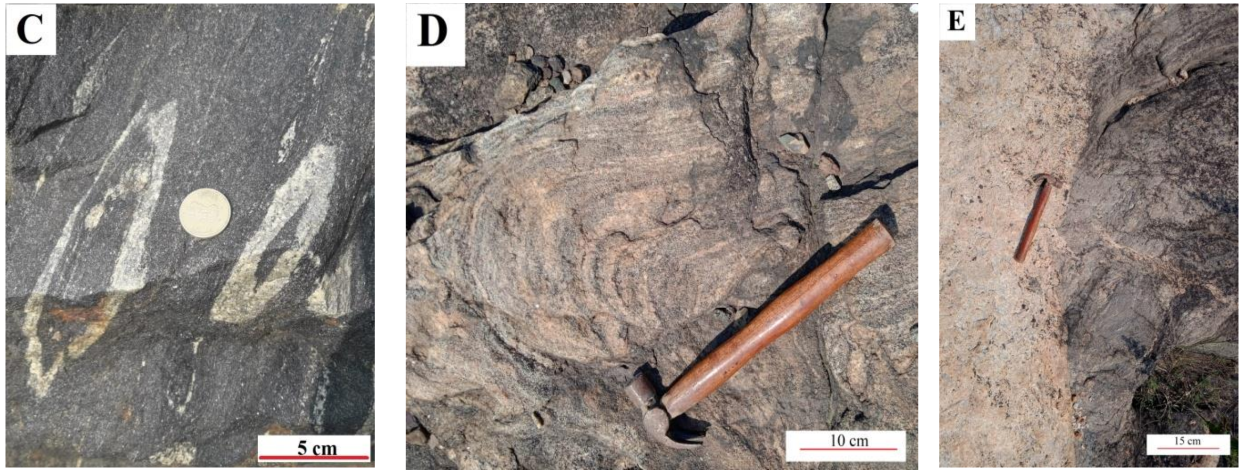


Fig: (A) Outcrop section of proto-mylonite shows mylonitic foliation (S), pervasive shear cleavages (C) and discrete shear bands (C'). (B) Proto-mylonite showing mylonitic foliation in WNW-ESE orientation with steep N- dipping marks the northern most part of SPSZ and prominent quartz veins are intruded in E-W orientation, feldspar porphyroclast showing top-to-left sense of shearing. (C) Porphyritic granite gneiss (Augen Gneiss) shows clear sinistral shear sense in megacrystic alkali feldspar grains where distinct rind and tail of recrystallized grains of same mineral in the highly strained part is clearly distinguishable. (D) Clearly distinguishable crenulation cleavage (S2) formed by Second generations of micro-folds (F2) in metapelitic rock (Phyllite) near Doladanga. (E) Mylonitic foliation (S) almost parallel to Shear Cleavage (C) along ENE-WSW striking, down dip lineation on shear cleavage steeply plunged towards N.



Folded layers showing stromatic banding of leucosome alternating with darker melanosome. Granitic leucosome (igneous origin) inside melanosome (metamorphic origin), migmatite in Kumari Dam, Balarsmpur district, Purulia.



Closed form fold, having sheath like appearance on plan view and Type – III (hook shaped fold) interferance patteren, contact between granite and basic granulite in Balarampur area.

Injection migmatite showing foliation-parallel granitic leucosome, having boudinaged structure and wing cracks implies extentional field regime.

Proto-mylonite showing mylonitic foliation along E-W to ENE-WSW direction and δ, σ type porphyroblast showing sinistral sense of shearing, Porphyritic granite shows deformation as megacrystic alkali feldspar grains (Kfs) form augens in augen gneiss.

Mica schist and low grade phyllite in Nekre village, Balarampur town (western part of SPSZ).

Mesoscale structures along NPSZ

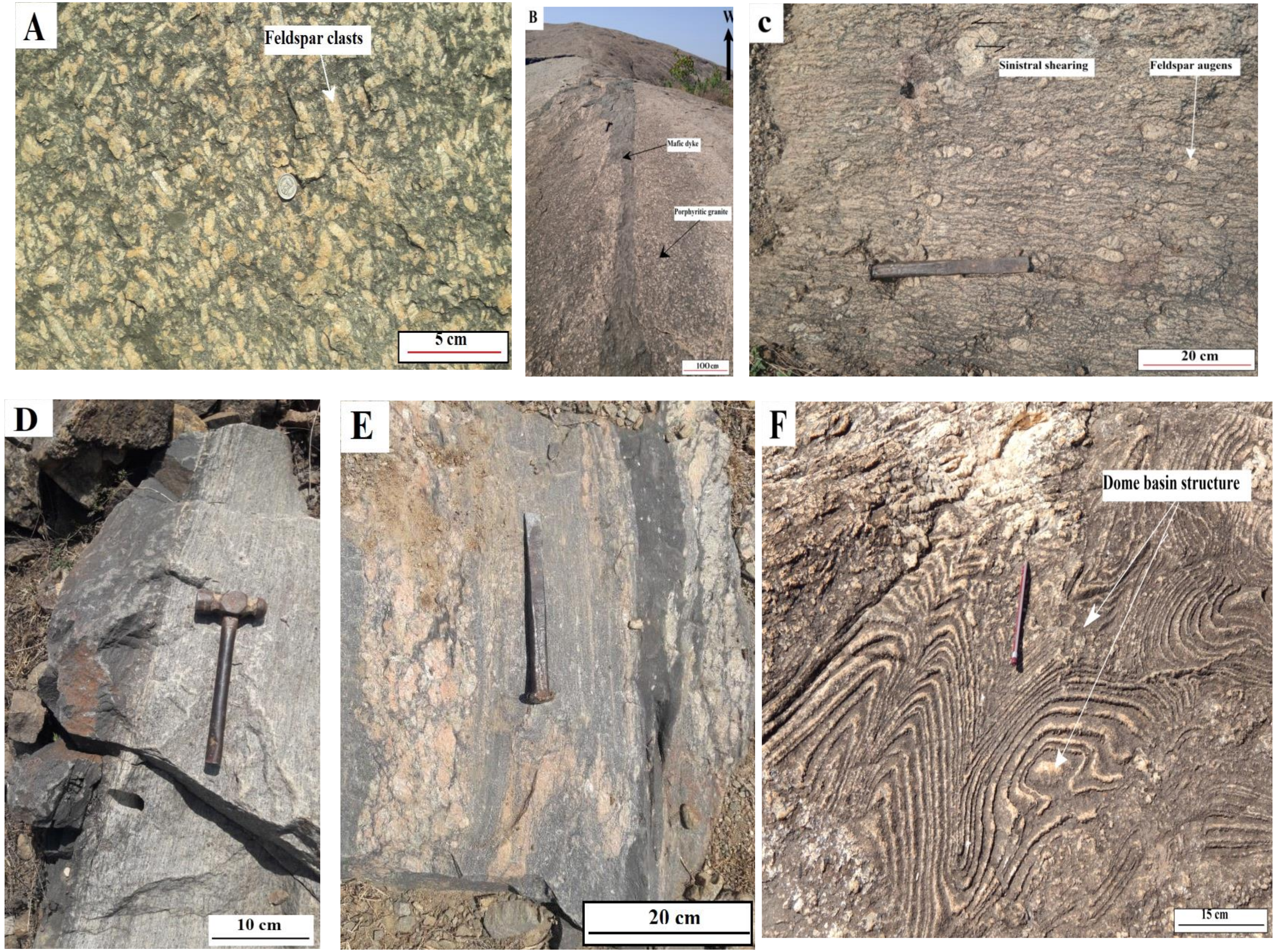


Fig: (A) Porphyritic granite contains very large rectangular feldspar grains near Raghunathpur College. (B) A large dolerite dyke intrude into Porphyritic granite in E-W orientation in later phase of deformation. (C) σ and θ type feldspar augens shows sinistral Sense of movement in mylonitized granite gneiss near Santuri in NPSZ forming S3 mylonitic foliation. (D) ENE-WSW trending gneissic foliation (S2) in Nepheline syenite defined by alternate thin dark bands intruded in to the mafic granulite in Bero Pahad. (E) Regional study reveals that high grade Granulites are intruded into the regional gneissic foliation (S1). (F) Dome basin structure found near Ananda Nagar formed due to different generation of fold superposition. (G) Garnetiferous Non-porphyritic granitoid protolith was injected parallel to the axial plane of the D1 -folds and metamorphosed to form the gneissic banding before the end of D1 –phase. Nearly E-W trending porphyritic granite identified by the preferred orientation of euhedral to subhedral feldspar (mainly microcline) + biotite + hornblende. (H) In Proto-mylonite s- type k-feldspar augens shows a sinistral sense of movement defined the northern boundary of the PGG batholith. Steeply dipping N mylonitic foliation striking in E-W orientation.

Microstructures along SPSZ

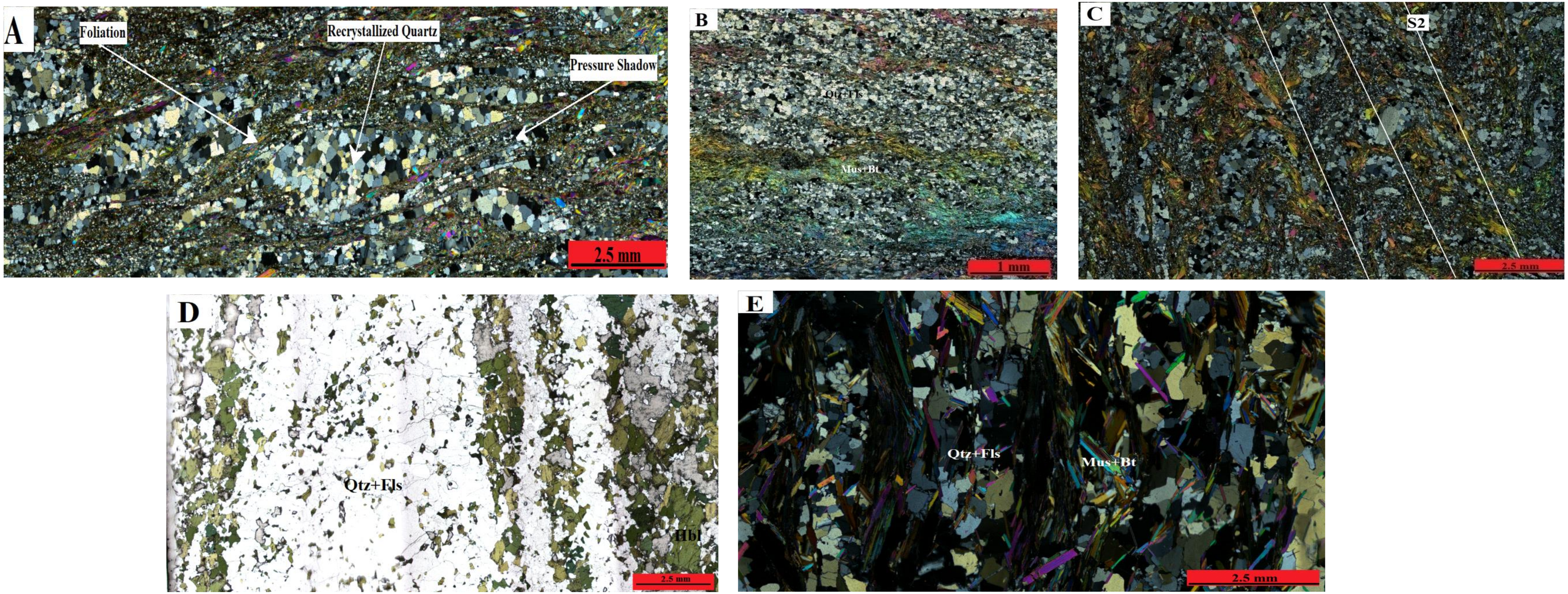
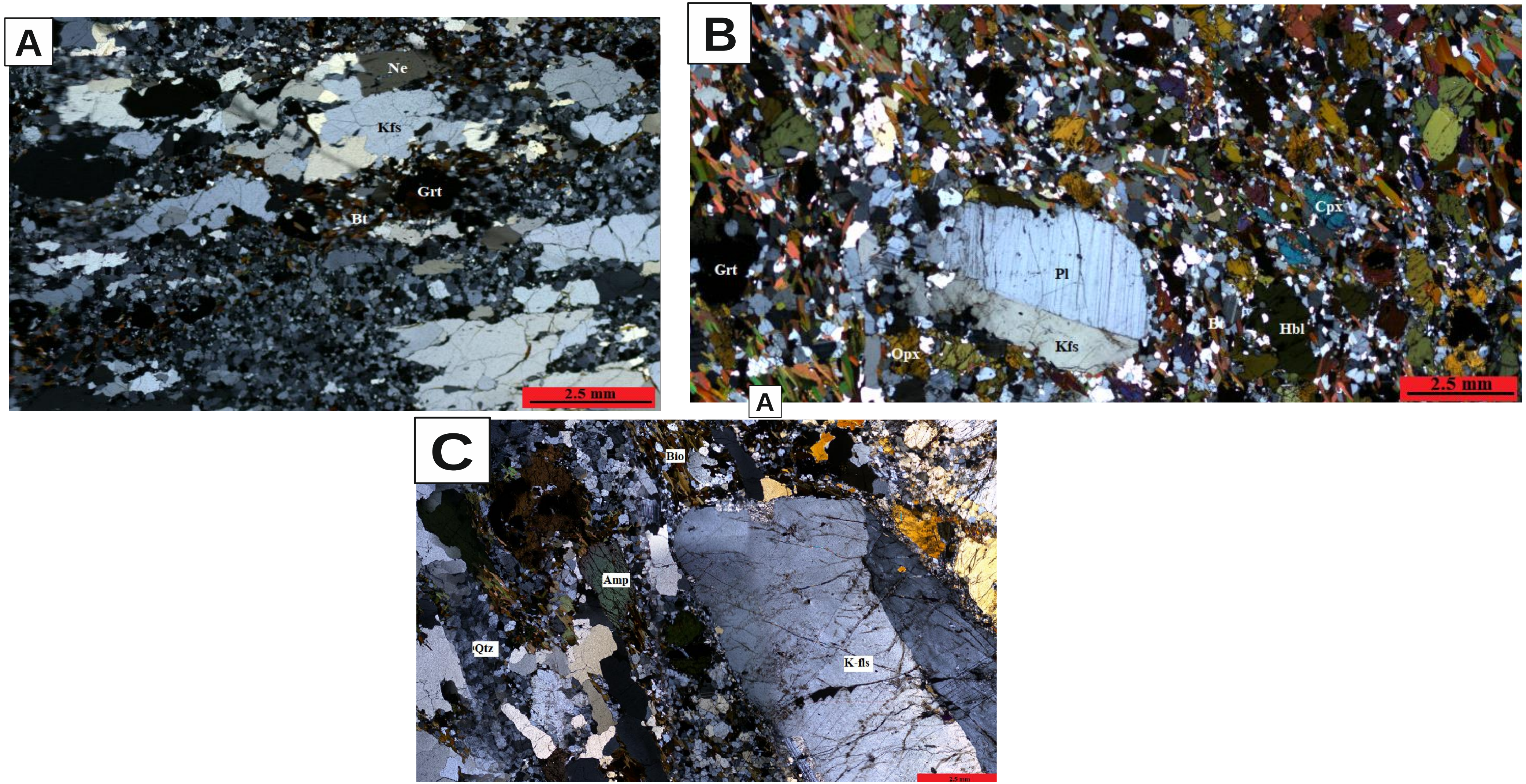


Fig: (A) Thin folia of phyllosilicates swerve around recrystallized quartz porphyroclasts in metapelitic rocks of SPSZ. (B) Few millimeter thick layers with abundant phyllosilicate minerals alternate with phyllosilicate-poor bands in phyllite of SPSZ. (C) Clearly distinguishable crenulation cleavage (S2) in metapelite of SPSZ. (D) Migmatitic bending, consist of melanosolomes rich in hornblende. (E) Mica schist of Nekre village showing clear Schistosity cleavages.

Microstructures along NPSZ



(A) Nepheline syenite showing distinguished bands of K-feldspar, nepheline and biotite, amphibole, pyroxene. (B) Basic granulite composed of Opx, Cpx, Grt, Plag, Hbl. (C) Large k-feldspar phenocrysts near Raghunathpurexhibits an abundance of biotite, amphibole, and k-feldspar, which are typical characteristics of Shoshonitic granitoids.

Major Structures of SPSZ

Location		Rock types	Structural features
South Purulia Shear Zone	E- Part of SPSZ (Kutni, Doladanga, Kharid1uara area)	low grade **Phyllites** (Mylonitized) in direct contact with **Granite Gneiss** (Augen-gneiss type)	**1st generation folds** Axial planar Schistosity (S_1) (Strike– ENE-WNW, dip– High angle towards N, Fold Axis (Intersection lineation) – gently plunging towards NW, **2nd generation folds** Minor folds and puckers on schistosity are amply developed along with an axial planar crenulation cleavage of two distinct orientations with NNE-SSW and NW-SE strike. These folds have low but variable plunge.
	W- Part of SPSZ (Balarampur area)	high grade **Mica Schists** intervene between the Granite Gneiss (migmatization) and the low grade Phyllites (Mylonitized)	**Inside mylonite zone** Major Folds is Reclined type, Mylonitic foliation (S) almost parallel to Shear Cleavage (C)– along ENE-WSE striking, downdip lineation on shear cleavage (Stretching lineation) – steeply plunged towards N, one set of shear band (C') - 35° to Shear Cleavage Minor folds are asymmetric and Tight to Isoclinal, Fold axis parallel to mineral lineation.
	Jilling (Center) (S. Bhattacharya, 1989)	low grade **Phyllites** (Mylonitized)	Minor Fold is symmetric and open, fold axis 30° to mineral lineation, mylonitic foliation is of the nature of a crenulation cleavage.
	Near Porapahar region (Chattopadhyay et al., 2016)	Metapellites (commonly phyllite)	Schistosity (S_1) trends 055–095° and dips 50–70° towards SE to S. At places, S_1 is first tightly folded with E–W axial trace (F_2) and then by a set of open folds with ~N–S axial traces (F_3).

Major Structures of NPSZ

Location		Rock types	Structural features
North Purulia Shear Zone	Raghunathpur, Santuri, Bero, Ramchandrapur, Ananda Nagar	Non-porphyritic granitoid gneisses, Khondalites	**1rd phase (D_1) of deformation** F_1 folds having moderate northerly dipping axial plane parallel to regional E-W foliation (S_1) in older metasedimentary rock that produces non-porphyritic granitoid gneiss by injecting anatectic granitoid melt parallel to S_1.
		Calc-silicate rocks, amphibolites, migmatites	**2rd phase (D_2) of deformation** S_1 refolded and formed ENE-WSW trending, N dipping tight, non-plunging, Overturned folds. F_1 & F_2 superposition forming various types of fold interference. Nepheline syenite emplaced parallel to the axial plane of F_2 fold.
		Mylonitzied granitoid gneiss, Alkali feldspar syenite	**3rd phase (D_3) of deformation** During D_3 deformation two parallel ENE-WSW trending regional shear zones (branches of the NPSZ) formed in Raghunathpur region. Mylonitic foliations are steeply dipping N with steeply plunging mineral lineation. Intensely foliated rocks, intense grain size reduction, S-C band, pinch-and-swell structure and rotations of porphyroclast mark the shear zone. The granulite facies terrain has been uplifted from deeper level along the shear zones and juxtaposed with amphibolite facies terrain during D_3-phase.

Tectonic settings of CGC

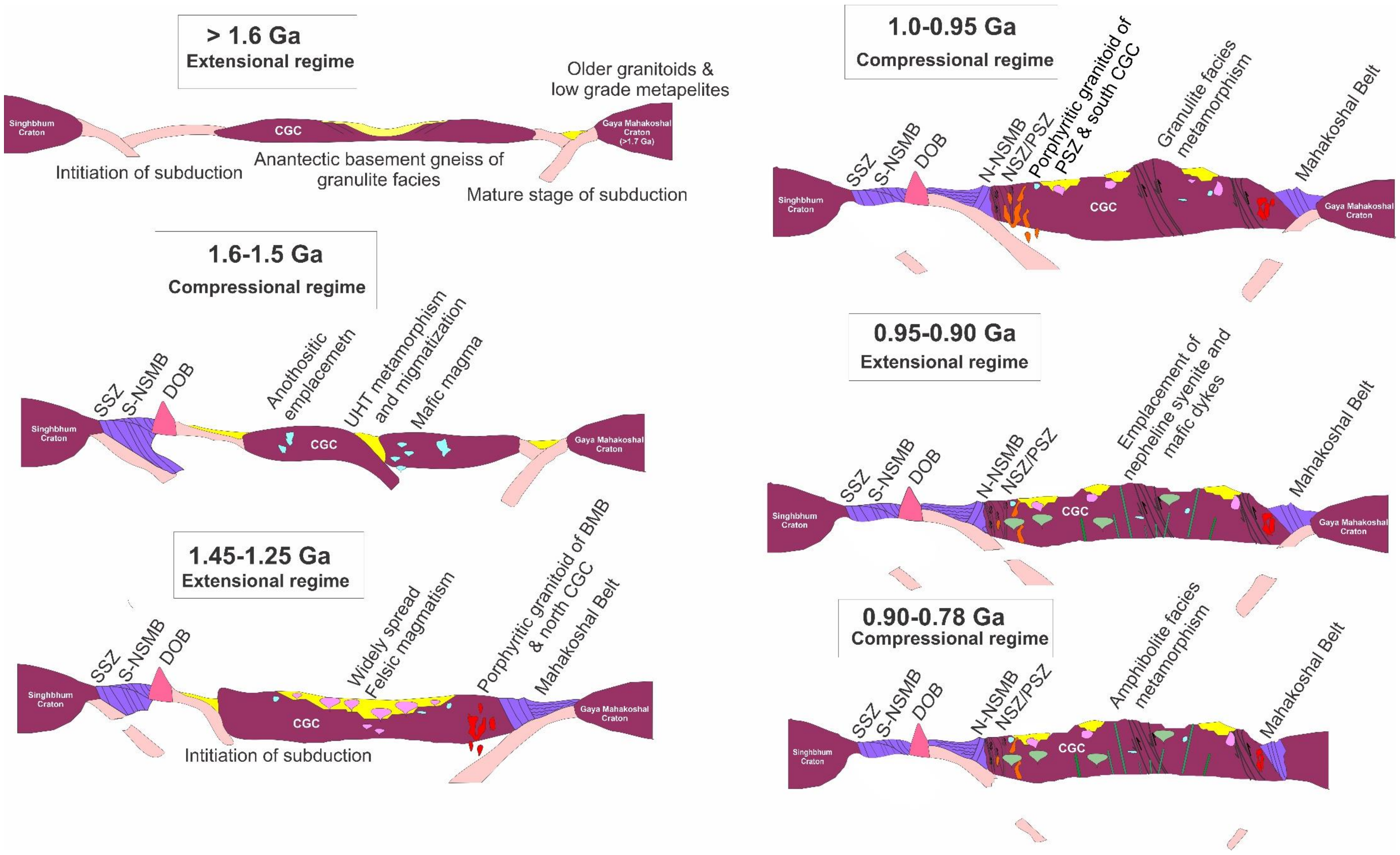


Fig. We have developed a tectonic model for the CGC that illustrates its Regional Tectonic Settings and evolutionary process. This model is based on a compilation of major events, and has been modified using information from several studies including Mukherjee et al., 2019, Das et al., 2018, and Sequeira et al., 2022. The model depicts six stages of compressional and extensional settings that the CGC experienced from the Paleo to Neo Proterozoic age, which also reflect the tectonic evolution of the eastern part of the Indian subcontinent. Overall, the model highlights the complex evolution of the craton and the impact of major tectonic events on its formation and development.

Deformation and Metamorphic history of CGC

Events	Igneous/ Metamorphic Activity	Deformational Event	P-T condition	Geochronology
Stage VI	Deformation of alkaline rocks in amphibolite facies metamorphism during continent-continent collisional orogeny (Das et al., 2018), formation of mafic dyke swarms (Mukherjee et al., 2018) Upper amphibolite-facies metamorphism (M_4) to produce amphibolite, foliated granite and augen gneiss. Pegmatite & leucogranite emplaced parallel to the axial planes of F_1-F_3 folds interpreted from the mafic dykes in the eastern part of CGC	Development of S_3 fabric southern part of CGC and local scale high strain zone along E-W to ENE-WSW (e.g. NPSZ) Development of the S_3 fabric in north–south orientation overprinted early granulite fabrics because of dominant F_2 folding indicates strong E-W compression in the eastern part	700-750 °C, 9–10 kbar (Das et al., 2018) 600-750 °C, 7 + 1 kbar in Josidih-Deoghar area (Ray et al. 2011) & 730-800 °C, 9–12 kbar in Dumka area (Chatterjee et al., 2010)	900-780 Ma 850-780 Ma (Sanyal et al. 2007) & 870-780 Ma (Chatterjee et al., 2010)
Stage V	Intrusion of Nepheline syenite, Alkali syenite, porphyritic granite and mafic dyke during rifting stage of Grenvillian basement crosscutting all the preexisting fabrics	Post-D_3 intrusion during the early Neoproterozoic	750-950 °C, < 7 kbar (Das et al., 2018)	950-900 Ma (Das et al., 2018)
Stage IV	Paleo Proterozoic basement along with the post D_1 intrusive, deformed under Granulite facies metamorphism (M_3) in continent-continent collisional setting Granulite to upper amphibolite facies metamorphism (M_3)	Development of thin gneissic banding (S_2) developed along east–west related to D_2 and D_3 deformations (Acharyya, 2003; Sanyal et al., 2007; Chatterjee et al., 2010)	850–900 °C, 8.5–11 kbar (Chatterjee et al., 2008) 850 °C, 9 kbar (Mukherjee et al., 2017) 870 °C, 11 kbar (Karmakar et al., 2011) 700 + 50 °C, 6.5 + 1 kbar (Maji et al. 2008, Sanyal and Sengupta, 2012)	1000-950 Ma 1200-930 Ma
Stage III	Intrusion of Charno-enderbitic magma, widespread plutonism of 1.5–1.4 Ga A-type granitoids (Sequeira et al., 2022) Intrusion of Gabbro-Anorthosite magma, porphyritic granitoid, syenite within ~1650 Ma high grade basement gneiss	Post- D_1 magmatism during Early Mesoproterozoic time	700-800 °C, 5–6 kbar (Pattison et al., 2003)	~1450 Ma (Mukherjee et al., 2017) ~1550-1500 Ma (Acharyya 2003; Chatterjee et al. 2008)
Stage II	High-grade metamorphism (M_2) causes formation of migmatitic charnockite gneiss by intrusion of granitoid into older M_1 granulites (Sanyal & Sengupta, 2012) Regional UHT metamorphism and partial melting of supracrustals during collisional orogeny Gray granites (porphyritic) intruded into unknown felsic basement with pelitic/calc-silicate supracrustal in Northern part of CGC (Bathani area) (Saikia et al., 2017)	Development of S_1 gneissic band in the regionally extensive gneisses during D_1 deformation	700-800 °C, 5–7 kbar 930-950 °C, 5–6 kbar 770-870 °C	~1660-1550 Ma (Dey et al., 2017; Sanyal and Sengupta, 2012) 1750-1660 Ma (Saikia et al., 2017)
Stage I	UHT Metamorphic event (M_1) that is recorded in granulite enclaves in E and SE regions of CGC recorded within migmatitic charnockitic/quartzofeldspathic gneiss (Sanyal et al., 2007; Sanyal & Sengupta, 2012)	Development of gneissic banding within granulite enclaves.	900-950 °C , 5-8 kbar	1870 Ma (Chatterjee et al. 2010)

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