Chapter 8. Summary

The structural pattern of the Meso-Proterozoic Champaner Supracrustals part of SAMB was believed to be very simple; the present work has not only revealed its structural complexities and tried to provide an insight to revitalise an understanding of the tectonics of Southern Aravalli Mountain Belt (SAMB), in context to the Champaner Group. The following points broadly enumerate the important findings of the study. The later part of this chapter discusses the probable reasons and proposes a tentative model of evolution of structures with respect to the Champaner Group.

8.1 Salient findings of the study

1. The Champaner Group shows three episodes of deformation, viz. D_1, D_2 and D_3, which has developed F_1, F_2 and F_3 folds respectively. The first two phases of deformation are coaxial, to develop F_1 ~ ESE-WNW and F_2 ~ E-W trending folds. The third episode of deformation exhibits fold trends ranging from NNW-SSE to NNE-SSW.
2. Apart from these trends, there are evidences of out-of-sequence deformation displaying F_1 ~ NW-SE to N-S and F_2 ~ NE-SW.
3. Combinations of various folds have generated interference fold patterns on regional and meso-scopic scale. Superimposition of F_1 and F_2 fold has resulted into Type III interference fold pattern, where as combination of F_3 has developed the Dome and Basin geometry (i.e. Type I). In case of out-of-sequence deformation Type II interference pattern has been generated over Type 0.
4. Followed by fold events, the rocks of the study area have been subjected to brittle faulting ranging from E-W to N-S direction in the form of radial pattern (Fig. 3.1). These faults have developed along the pre-defined axial traces due to the granitic emplacement in the SE and E extremity of the study area. Manifestation of strike slip faults in cross-section has resulted in to top-to-east reverse shears.
5. Magnetic foliation derived through Anisotropy of Magnetic Susceptibility (AMS) analyses corroborates well with the field reading. This suggests that, by and large, the bedding and the

foliation in the study area is parallel/ sub-parallel to each other. In case of minor fluctuations, the rock acquired the imprint of last deformation occurred within the Champaner Group though their meso-scale evidences have not been registered within the present terrain.

6. Microstructural studies reveal the evidences of all deformational events within the rocks of the Champaner Group. Moreover, effect of heat on account of the granite emplacement has left its imprints on microstructural features.
7. Temperature and/or strain induced microstructures show sequential development from west to east, within the quartzites of the Champaner Group. These microstructures include, Bulging Recrystallization (BLG); Subgrain Rotation Recrystallization (SGR); Grain Boundary Migration Recrystallization (GBM) and Grain Boundary Area Reduction (GBAR), respectively. The quartz grains in quartzites, in vicinity of the granites, show undulose extinction along with grain coarsening. This anomaly signifies that though the temperature was extravagant, there existed high strain rate which did not allow mineral to remove its dislocations.
8. Shear Induced Microstructures recorded form the cross-sectional reverse shears display variety of shear sense indicators. An uncommon opaque (ilmenite) porphyroclast has been used to decipher the shear direction. These shear sense indicators include shear band cleavage, mantled porphyroclast systems ~ σ and δ of stair stepping variety and φ type porphyroclasts with strain shadows, and varieties of fishes from Group 1- 6, quarter structures and pinch and swell microstructures.
9. Complex microstructures in the form of Oppositely Concave Microfolds (OCMs) are also seen on account of top-to-east shear present within the terrain.
10. Microstructures related to syn-tectonic granite emplacement are highlighted into two broad heading (1) low temperature solid state deformation, showing presence of undulose extinction in quartz and biotite; kinking in biotite; micro-faulting and fracturing in crystals and micro-folds within mica minerals of granite. (2) high temperature solid state deformation, indicating features like chess-board extinction of quartz.

11. As far as metamorphism is concerned, the area has witnessed regional metamorphism up to greenschist facies condition by the development of chlorite and biotite during D_1 deformation. The D_2 phase of deformation has resulted into the development of garnets within the meta-pelites of the region. There is no mineral development during D_3 phase of deformation. The grade of regional metamorphism increases from west to east by the development of chlorite-biotite-garnet.
12. The Champaner terrain has been affected by protracted phase of emplacement of granite. The syn-to-post tectonic pulse has resulted into various over-printing relationships of contact metamorphic textures on regional metamorphic textures. Minerals developed due to syn-tectonic pulse include andalusite, cordierite and sillimanite (fibrolite), where as the post-tectonic pulse culminated into metasomatic changes by developing minerals such as muscovite and tourmaline. Hence, it can be said that the contact metamorphism has reached up to pyroxene-hornfels facies conditions.
13. Results from microtremor studies specify that there exists granite pluton beneath the Champaner meta-sediments. The pluton has not only deformed the overlying country rocks, perhaps uprooted the Champaner meta-sediments. The estimated vertical thickness of Champaner metasediments varies between 30-100 m and goes to a maximum of 136 m at the Shivrajpur Manganese Mine area.
14. Modal composition of the granites present in and around Champaner Group categorise them monzogranite to granodiorite variety. Based on the geochemical records, these granites point towards late-orogenic to post-collision uplift sub-field of syn-collisional granites. Zircon saturation temperature (Zr-M) plot indicates that the average temperature of granite magma was 816.8^{o} C.

8.2 Probable reasons and Structural Evolution

The structural setup of the Champaner Group shows consanguineous contiguity has been matched with the existing structural setup of the Southern Aravalli Mountain Belt, which includes, a. the Banded Gneisses located at the NE; b. the Lunavada Group at the north; c. the Pre-Champaner

Gneissic Complex (PCGC) located at the SE (Chhota Udepur region); d. the Godhra granites. Table 8.1 shows the summary of various trends recorded from neighbouring Proterozoic Supracrustals and its relationship with the study area. The highlighted columns within the table indicate correlatable axial trace trends within the Southern Aravalli Mountain Belt (SAMB)**.** Based on the available records it is evident that the structures in the area show correlatable axial trace trends of D_1-D_2 coaxial deformation with the D_3 deformation of banded gneisses located at the NE and Lunavada region located at the N; D_2-D_3 deformation of the Pre-Champaner Gneissic Complex (PCGC) located at the SE (Chhota Udepur region), and the deformational trends within Godhra granite. In case of D_3 deformation of the Champaner Group, the correlatable trends exist with the D_4 deformation of the Pre-Champaner Gnessic rocks. Hence, it can be said that the Champaner orogeny started during the waning orogenic phase of the banded gneisses and the Lunavada Group, while it is correlatable with the mid orogenic phase of the PCGC. Finally the closing of Champaner Orogeny was coeval with the PCGC rocks resulting into broad open warps and kinks due to post granitic pulse.

In order to assess the probable causes of the fold trends recorded from the Champaner Group, the proto-continent accretion concept (primarily given by Naqvi *et al.*, 1974; Rogers, 1986; Radhakrishna and Naqvi, 1986; Naqvi and Rogers, 1987) for the Aravalli, the Dharwar and the Singhbhum proto-continents has been used. The ‘Y’ shaped lineaments viz. the Narmada, Son and Godavari, along which the Aravalli-Dharwar, the Aravalli-Singhbhum and the Dharwar-Singhbhum proto-continents accreted respectively, during the Meso-Proterozoic times. Based on this, a “Working Model” or “Working Hypothesis” given by Mamtani *et al.* (2000) in terms of deformation pertaining to the Southern Aravalli Mountain Belt clearly suggests that, there is an impact of accretionary event on southern part of the Aravalli proto continent. The manifestation of which is in the form of changes in the structural trends and growth of metamorphic minerals. Further the model illustrates that the E to NW trending structures in SAMB formed suturing between the Aravalli and the Dhrawar Protocontinents (ca. 1400-935 Ma).

The Banded Gneisses located at NE	The Lunawada Group located at the N	The Pre-Champaner Gneissic Complex (PCGC) located at the SE (Chhota Udepur region)	The Champaner Group (Study Area)	Godhra Granite
D1 and D2 Coaxial having Axial trace trend NE-SW to ENE-WSW	D1 and D2 Coaxial having Axial trace trend NE-SW	D1 having Axial trace trend N-S of Recline folds	-------------	--------------
D3 having Axial trace trend ESE-WNW to ENE-WSW	D3 having Axial trace trend E-W to NW-SE	D2 and D3 having Axial trace trend E-W with different fold morphology (a. Recline & b. Upright)	D1 and D2 Coaxial having Axial trace trend F1~ENE-WSW F2 ~ E-W	Preferred Orientation of feldspar laths trend ESE-WNW; Magnetic Foliation trend ESE-WNW to ENE-WSW
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Table 8.1: Summary of deformation events recorded in neighbouring Precambrian Supracrustals and its relationship with the study area. Structural records from the Banded Gneisses and the Lunawada Group (Mamtani, 1998 and Mamtani et. al., (1996a,b, 2000, 2005); the data from the Pre-Champaner Gneisses (Karanth and Das 2000); Godhra granite magnetic data and preferred orientation of feldspar laths (Mamtani and Greiling, 2005; Mamtani et. al., 2002; Sen and Mamtani, 2006). Highlighted columns in the table indicate correlatable axial trace trends within Southern Aravalli Mountain Belt (SAMB).

In case of the present study, the N-S to NNE-SSW shortening direction generated on account of the suturing has led to the development of ESE-WNW to E-W trending structures across the Champaner Group. Furthermore, the area located at the core of the Champaner Group has experienced intense compression due to regional deformation, engendering refolding of earlier folds and imparting westerly plunge to F_1 and F_2 folds (Fig. 8.1a). The concept of protoplate tectonics has been visualize to explain the deformational patterns observed in the southern parts of the Delhi Fold Belt (DFB) (by Sychanthavong and Desai, 1977; Sychanthavong and Merh, 1981, 1985; Sychanthavong, 1990).

Granites located in and around the Champaner Group of rocks display signatures of syn to post plutonic emplacement (Joshi and Limaye, Inpress). Distinguishing characteristics of syn/ post-tectonic granites can be very well appreciated in the area east of the Jhand, where coarse-grained post-tectonic granites show intrusive relationship with the fine-grained syn-tectonic granites (Joshi and Limaye, 2014). The coeval pulse of granite emplaced during progressive deformation has magnetic foliation trending WNW to WSW (Fig. 2.2). Feldspar laths within syn-tectonic granites too trend WNW to W striking trends (Mamtani 1998; Mamtani et al., 2002; Mamtani and Greiling, 2005; Sen and Mamtani, 2006). Geochemical analyses of granites carried out in the present study and existing geochemical records of syn-tectonic granites suggest that the granite is of ‘S-type’ evolved on account of partial melting of the continental crust during continent-continent collision (C-C) (Fig. 8.1a) (Merh 1995; Goyal *et al.*, 1997).

The granites of post-tectonic nature is characterised by forceful emplacement deforming the country rocks along N-S trend and developed strike slip faults of sinistral/ dextral nature along pre-existing axial planar weak zones throughout the group (Fig. 3.1) (Fig. 5b). The model given by He *et al.* (2009) for Fangshan pluton, SW Beijing, forms the rim syncline along the margin of the pluton. Similar style of N-S trending rim synclines are found to be developed along the eastern margin of the Champaner Group bordering the pluton. The post tectonic granites having the geochemical affinity of ‘A-type’ representing transitional or post-orogenic uplift (suggested by Maithani *et al.*, 1998; Goyal *et al.*, 2001), has been intruded by accommodating the space within the Champaner metasediments and pre-existing syn-tectonic pulse (Fig. 8.1b). Such inferences have been derived by collecting xenolith evidences of (i) Champaner meta-sediment and (ii) fine grained granite from coarse grained granite variety (Figs. 3.10c-f). One such location is at the north-eastern fringe of the Champaner region near Sukhi dam, where intrusive contact between Godhra granite and Champaner meta-sediments is exposed (Fig. 3.9e).

Geophysical studies carried out using Microtremor technique suggest pluton hump exactly below the Narukot dome. The surface manifestation of pluton hump can be corroborated by the development of the cross-sectional reverse shear having top-to-east shear sense, in vicinity of the Narukot dome (Fig. 3.1). Structural setup of the Jothwad region located in the eastern extremity of the study area depicts signatures of out-of-sequence deformation due to post-tectonic granite. Though the Jothwad region, part of the Champaner Group represents superimposition of Type-II interference pattern over cylindrical upright fold, this interference fold patterns is rootless and connotes no continuity in the subsurface as well as are unmatched with the existing structural set up of the Champaner Group (Joshi and Limaye, Inpress).

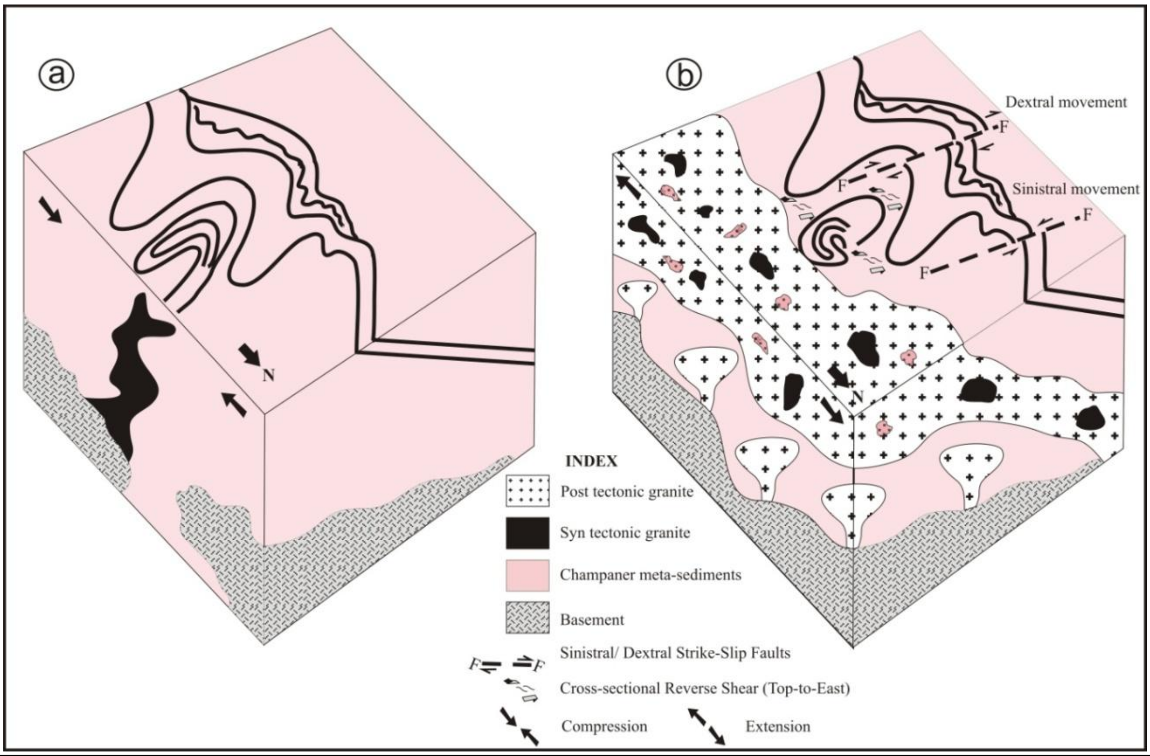

Figure 8.1. (a) Cartoon showing suturing of proto-continents and refolding of earlier folds along with the plunge on account of regional deformation as well as emplacement of syntectonic granite; (b) Closing up of earlier refolded folds orthogonally and development of sinistral/ dextral faults along the pre-existing axial planes due to post intrusive pulse. Granite of post-tectonic nature holds xenoliths of Champaner meta-sediments and earlier syn-tectonic granite. These cartoons have been modified after winter 2012.

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