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Geometry of Fold Structures and Their Interference Patterns in Banded Iron Formation of Eastern Limb of Bonai-Keonjhar Belt, Odisha, India

D. Beura[1,*], B. Satpathy[2]

[1]P.G. Department of Geology, Utkal University, Bhubaneswar
[2]TISCO, Joda
*Corresponding author: debanandabeura@rediffmail.com

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Abstract The Bonai-Keonjhar belt of Odisha is famous for its potential iron formation that lies in the western flank of the North Odisha Iron Ore Craton (NOIOC). This horse shoe shaped belt having two limbs form a distinct 'U'-shaped pattern, which is considered as the youngest Iron Ore Group. Banded Iron Formation (BIF) of the Precambrian age occurs in huge amount in the belt comprising of alternate layers of iron bearing minerals and silica along with iron ores and associated rocks. The abundant lithomembers of the study area that comprise of banded hematite jasper, banded hematite quartzite, banded hematite chert, banded shale and ferruginous shale are un-metamorphosed and lack of any intrusive. The general structural disposition of the rocks of the belt is a synclinorium trending NNE-SSE direction having low plunge towards NNE. The rocks of the area are experienced with prolonged deformations correlated with iron ore orogeny and impact has been manifested in form wide range fold geometry. The structural disposition and pattern of the study area consist of three distinct types of folds, which represent deformation history of the area and individual geometric dissimilarity. One set of folds is found to be open upright folds of symmetric or asymmetric nature. The second set consists of tight isoclinal folds, which are horizontal or overturned. The third set comprises of more open folds with broad warps. Such folds of three generations have been superimposed to produce different types of interference patterns.

Keywords: *Banded Iron Formation, fold geometry, BK belt, Odisha*

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1. Introduction

Iron ore is one among the other mineral resources that occur in huge quantities in vast geographical area of Odisha. It is mostly formed from the banded iron formation, which is considered as the host rock. The iron formation of north Odisha being designated as Iron Ore Groups in three separate provinces form the Iron Ore Super Group that occur in the periphery of the North Odisha Iron Ore Craton (NOIOC). These three iron ore bearing provinces are Badampahar-Gorumahisani-Suleipat belt (BGS belt) in the eastern border, Bonai-Keonjhar (BK belt) in the eastern side and Daitari-Tomka belt (DT belt) in the southern flank (Figure 1). Bonai-Keonjhar belt popularly known as Horse-Shoe belt of Keonjhar district of Odisha has the highest proven iron ore deposits to cater the iron and steel industries and export trade of the country. The Horse Shoe belt having two limbs extends from Gua (22° 13' N; 85°23' E) in Jharkhand in North up to Chelliatoka (21° 44' N; 85° 09'E) in the south, from the west runs east ward up to Malangtoli (21° 48'N, 85° 19'E) where from it turns northward to Noamundi (22° 09'N; 85° 29'E). The Banspani-Jilling-Jajang area comes under eastern limb of the 'U'-shaped Bonai-Keonjhar synclinorium, which lies in the western flank of well-known North Odisha Iron Ore Craton (Beura,2002; Beura and Singh, 2005; Beura et al., 2007). The eastern limb also contains Thakurani, Joda, Jaribahal, Malangtoli deposits (Figure 2.A). The eastern limb in general and Banspani-Jilling-Jajang area (latitude-21°55′00″-22°00′00″, longitude- 85°25′00″- 85°26′00″) in particular had been taken up for study where the Banded Iron Formation (BIF) is well noticed in association with iron ore and other rocks. The BIF and the associated litho-types of the study area belong to youngest Iron Ore Group (BIF-III) under Iron Ore Supergroup of north Orissa (Acharya, 1984 & 2000; Beura, 2002). The rocks of the area have undergone poly-phase deformation and have not suffered a little metamorphism. The general trend of rocks of the study area is NE-SW.

The lithomembers of BIF of the area include Banded Hematite Quartzite (BHQ), Banded Hematite Jasper (BHJ), Banded Hematite Shale (BHS), Banded Shale, Banded Manganese Formation (BMnF), ferruginous shale and Iron ore bodies. Banded Hematite Jasper (BHJ) and Banded Hematite Quartzite (BHQ) are characterized by alternate bands of iron mineral and silica of varying thickness (Satpathy and Beura, 2011). Banded shale shows bands of different colours and occurs at the base of BIF. The ferruginous shales younger to BIF discontinuously occur in the area. The phyllites and shales are of carbonaceous in nature.

Hematite, martitised magnetite, martite, specularite and goethite are the prominent iron minerals that the BIF and iron ore contain. Chert, jasper and quartz are the forms of silica. The primary iron minerals have undergone marititisation, goethitisation and hematitisation to form the other iron minerals. Hematite is the leading iron mineral in the study area. The BIF and the iron bodies comprise primary depositional, post depositional and diagenetic features.

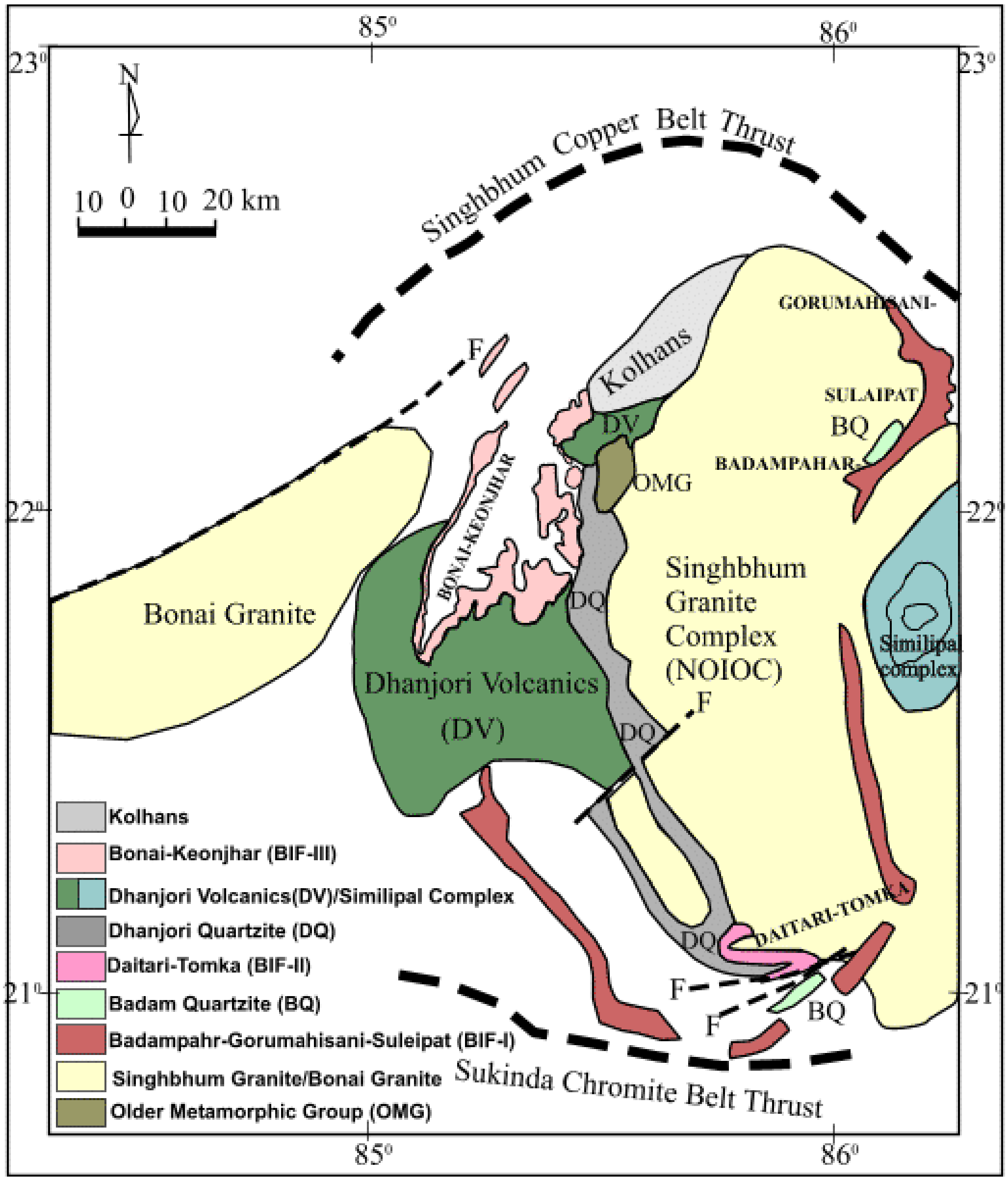

Figure 1. Generalised geological map showing BIF-I, BIF-II and BIF-III (Modified after Jones, 1934; Beura, 2014)

2. Geology

Banspani-Jilling–Jajang area in the eastern limb of the BK belt belongs to youngest Iron Ore Group of Odisha. It is located along the western margin of the eastern limb BK Belt (Figure 2. A). The litho-associations of this area form the youngest Iron Ore Group in the Iron Ore Supergroup of Odisha and is named as BIF-III (Acharya, 1984, 2000, 2005). The IOG designate BK belt largely contains BIF of the Precambrian. In addition, the other volcano-sedimentary rocks form a significant portion of the Singhbhum–North Orissa Craton of eastern Indian shield (Saha et.al, 1988). This IOG also contains other rock units like two generations of shales, tuffs that underlie or are interlayered with BIF (Figure 2.B). The BK belt has been named differently such as Barbil Group (Iyengar and Murty, 1982), Koira Group (Murty and Acharya, 1975) and Khondadhar group (Sarangi and Acharya, 1975).

In Banspani-Jilling–Jajang area several economically significant tabular strata bound bodies of high-grade hematite ores are found, which are proficiently hosted by the BIF across the area. At places massive iron ores comprising of hard and laminated types of varying thickness occur just above the BHJ. Still the possibility of iron ore below the BHJ cannot be ruled out as multiple generations of shales occur rhythmically as markers within the IOG.

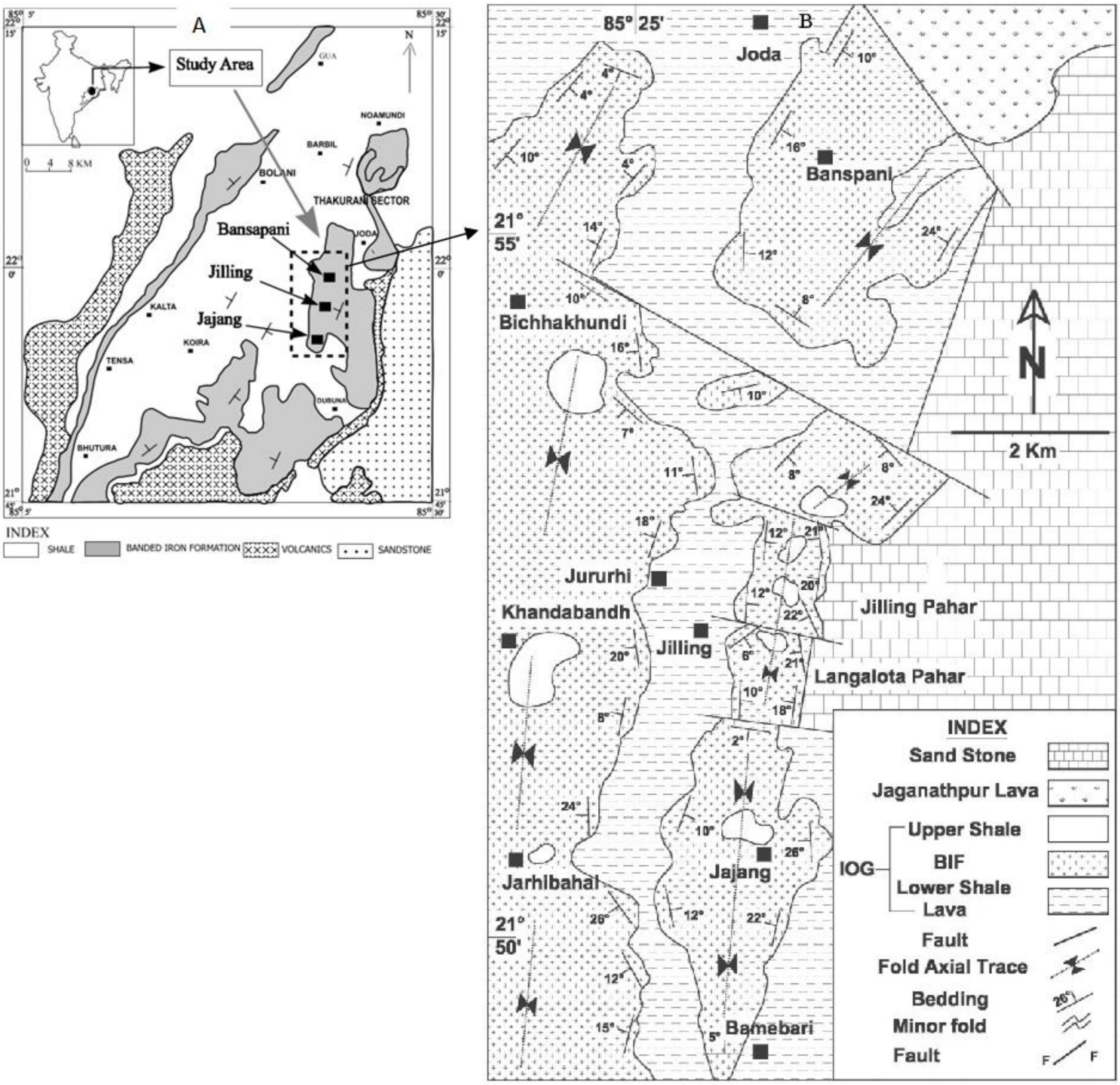

Figure 2. A. Generalized geological map of Horse shoe belt B. Geological map of Banspani-Jilling-Jajang area (Modified after Ghosh & Mukhopadhaya, 2007 & Beura et al., 2012)

The iron formations of this area in general have not attained metamorphic transformation. This may be one of the criteria suggesting it to be the youngest among the three BIFs. The very rare event with regards to metamorphism encountered in the area is that the rocks suffer from extremely low grade metamorphism. The general trend of the study area is in NNE direction having low plunge. The structure of the rocks of this area is dominated by several fold movements. The axis of the major fold is N-S. Rocks are subjected to polyphase deformation with maximum of three phases of folding. This has resulted in forming various interference fold patterns. The ore bodies are laid down in the synform with their axes plunging due south and north. Specifically in the Langalota ore body, the northern part plunges due north and southern part plunges due south. The area encounters random faults of various dimensions trending in N-S direction.

3. Geometry of Structures

Three distinct types of folds have been traced in the study area, which are the outcome of poly phase deformations. Formation of successive fold structures represents the deformation history of the area and individual geometric dissimilarity. The first phase fold structures are found to be open upright folds of symmetric or asymmetric nature while the second phase consists of tight isoclinal folds, which are horizontal or overturned. The third phase folds comprise of more open folds with broad warps.

As has been discussed by the earlier workers the Bonai-Keonjhar belt is folded into a major NNE plunging syncline, which is popularly known as the Horse Shoe syncline. It is overturned towards east (Jones, 1934) and cross folded along an E–W axis (Sarkar and Saha, 1962, 1977; Chatterjee and Mukherjee, 1981; Saha, 1994; Mukhopadhyay, 2001). But according to Sengupta et al. (1997) the BIF of Horseshoe syncline occurs as a gently folded sheet rather than as an overturned syncline. The generalised structural map of the BK belt indicates regional morphostructural pattern as well as the geometry (Figure 3). The detailed structural map of the study area, which has been prepared out of detailed mapping, presents the structural elements and geometry (Figure 4). The structural analysis of the tree major sectors has been done by undertaking the synoptic distribution and orientation of bedding poles and fold axis at respective places (Figure 5).

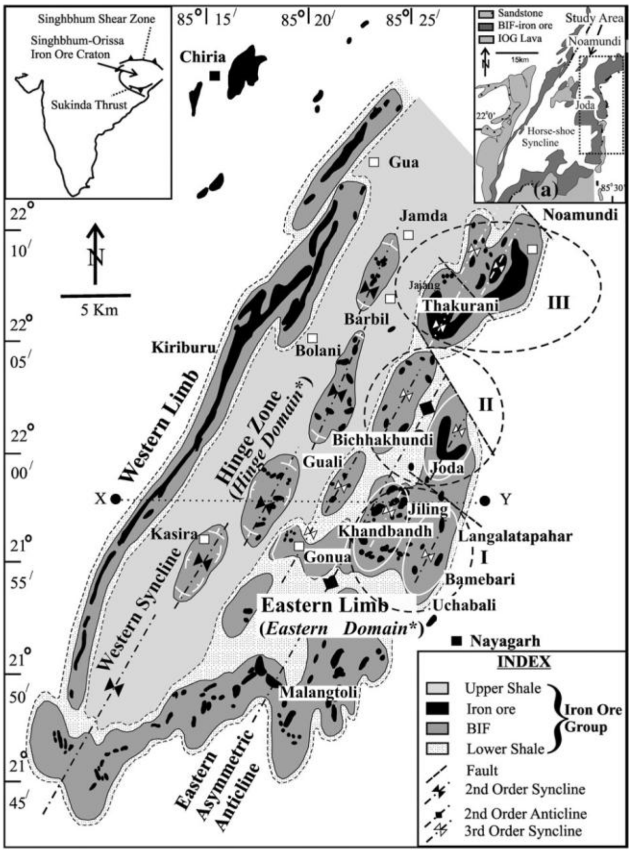

Figure 3. Generalized Structural map of BK belt (BIF-III) (modified after Jones, 1934; Ghosh & Mukhopadhaya, 2007)

3.1. Structure of First Generation

The earliest recognizable diastrophic structures in the area are open folds (F_1) with axial plane schistosity (S_2) and linear structures (L_1) parallel to the F_1 fold axes (Figure 6. A). The F_1 folds are on stratification (S_1) ranging in size from few cm. to more than a metre. The axial planes of F_1 folds mostly show N-S strike with gentle dip of 6° to 18° towards either north or south. The linear structures parallel to the axes of F_1 folds are fold mullion and boudinage structures and lineation due to intersection of stratification (S_1) and axial plane schistosity (S_2).

3.2. Structure of Second Generation

The second-generation folds (F_2) are scattered in the study area with varying dimensions and on different litho units. The subsequent deformation acted on F_1 could develop F_2 fold, which is vectorally contrasting in nature. As a result the S_3 cleavage is perpendicular or nearly perpendicular to the S_1. These folds are tighter than first folds and become isoclinal in many places (Figure 6.B). The F_2 folds are usually overturned with the axial planes strike along E-W direction with variable low plunges (5-18°) in both east and west directions. The linear structures of the second generation are the axes of small folds and puckers on S_1 schistosity with their axes parallel to the F_2 fold axes.

3.3. Structure of Third Generation

The F_3 folds are found at places with broad warps in the study area. The axial planes (S_4) are developed trending N-S with gentle dips (5-12°) towards north and south directions (Figure 6. C). At some places fractures are developed parallel to the axial planes (S_4) of F_3. The axial plane of the F_3 fold along with S_4 cleavage has been involved in coaxial upright folding (F_1) throughout the area.

Sometimes all the tree folds of different generations i.e. the first, second and third generation fold structures are noticed together architecting a single complex fold (Figure 6.D).

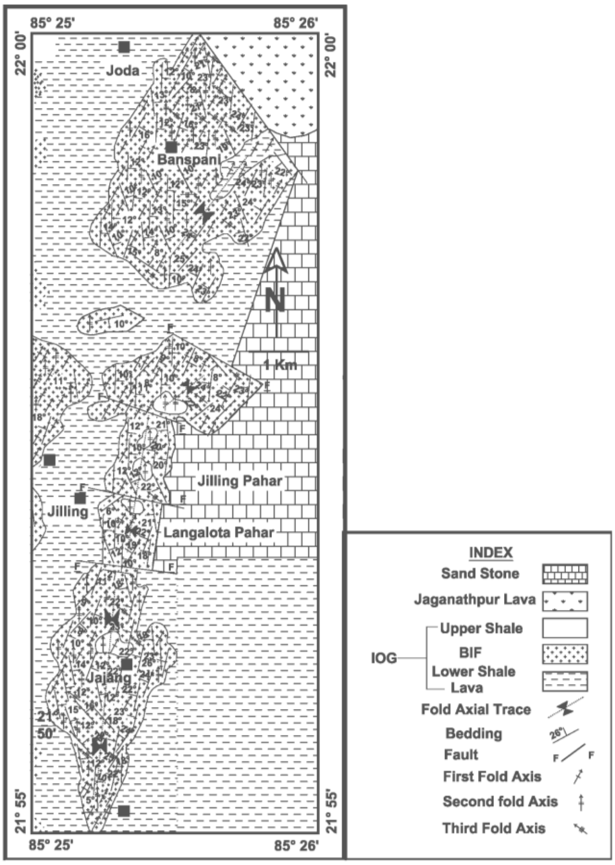

Figure 4. Structural Map of the study area

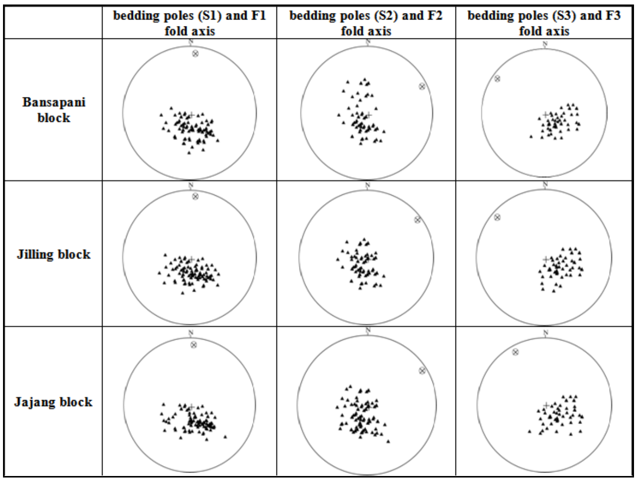

Figure 5. Synoptic distribution and orientation of bedding poles and fold axis at places mentioned above

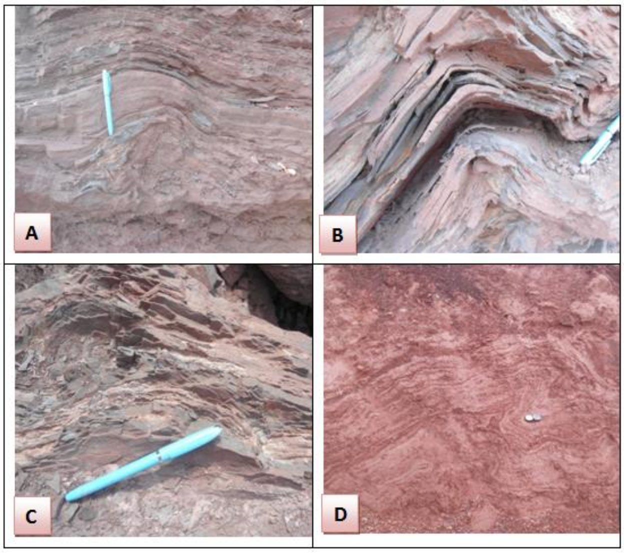

Figure 6. Field photograph showing different phases of fold structures

A. F_1 parallel folds in Bansapani

B. F_2 chevron fold at Jajang

C. F_3 folds at Bansapani

D. F_1, F_2 and F_3 folds in Jilling

4. Pattern of Fold Interference

The folds of three generations have been recognised in the study area. The earliest fold is the first-generation fold (F_1) structure and the folds (F_3) with NS striking axial planes are congruous with it. The major fold (F_2) is a refold of earlier fold (F_1). The second phases of folds (F_2) with axial planes striking in E-W direction have modified the geometry of the earlier folds. Different types of interference fold patterns produced by successive phases of deformation are well observed.

4.1. Eye Patterns

The eyed folds well seen in Jajang-Langalota sector are produced due to the interference of F_2 fold on F_1/F_3 folds (Figure 7. A). These folds are developed as a result of strong later compression of earlier folds having initial non-rectilinear axes (Mukhopadhyay and Sengupta, 1979). The eyed folds are the planar view of the three dimensionally developed dome and basin (Type-1 of Ramsay, 1967) interference structures with variable styles.

4.2. Mirror Image Folds

This is an interference fold pattern producing triangular outcrop pattern. Non-isoclinal folds are converted to mirror image folds due to the shifting of axial surface of the subsequent generation of folds (F_3) on either side of the axial trace of the first generation of folds (F_1). The mushroom folds are similar to this mirror image folds (Type-2 of Ramsay, 1967) (Figure 7. B).

4.3. Hook Folds

The hook shaped fold pattern are the outcome of interference of F_1 and F_2 folds well noted at Jilling-Gangaigora sector. The curve axial trace of F_1 folds due to the interference of F_2 generates hook shape folds (Type-3 of Ramsay, 1967) of double closures (Figure 7. C).

4.4. Dome and Basin Patterns

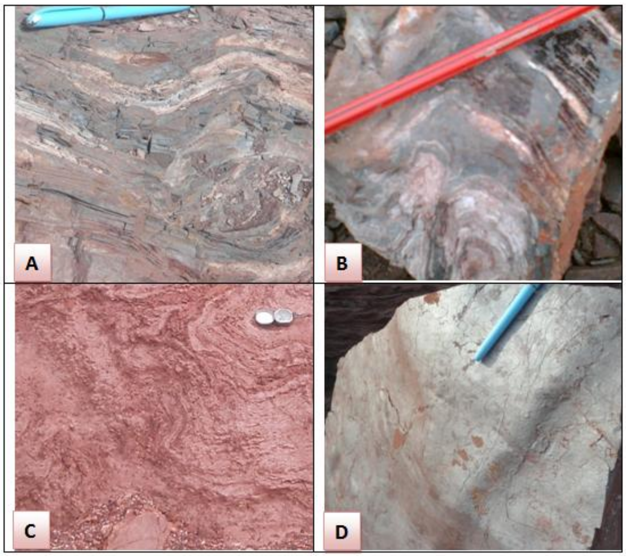

Figure 7. Field photograph showing interference fold patterns

A. Eye shaped folds at Jajang-Langalota

B. Mirror shaped fold at Bansapani

C. Hook fold at Jajang-Langalota

D. Domes and basins at Bansapani

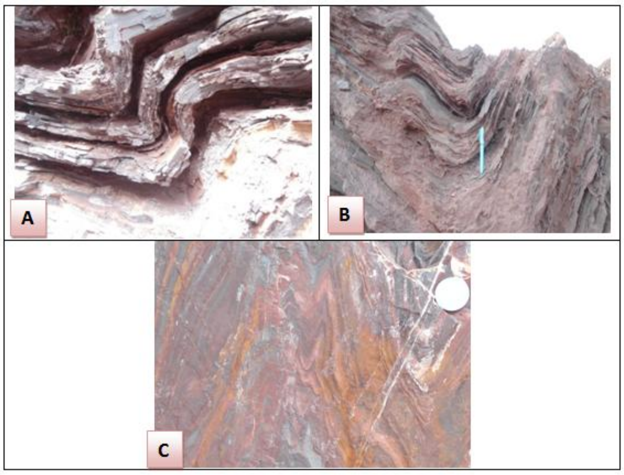

Figure 8. Field photograph showing minor interference fold patterns

A. S shaped fold

B. Z shaped fold

C. M shaped folds

The dome and basin patterns (Type-1 of Ramsay, 1967) are seen around Bansapani sector. These are associated with isoclinal F_1 and F_3 folds interfering with F_2 folds (Figure 7. D). The long diagonals are parallel to the F_1/F_3 axial trace. It is suggested that F_1 structures with planar axial surfaces and highly curved axes are developed as a result of strong later compression of F_2 fold having initial non-rectilinear axis (Mukhopadhyay and Sengupta, 1979).

The minor folds of 'S', 'Z', and 'M' shapes related to the three deformations have been traced at different localities (Figure 8. A, B & C). As a result, varieties of shape combinations (Ramsay, 1967) have been developed during the superposition of the later folds on the earlier ones.

5. Discussion and Conclusion

Banspani-Jilling–Jajang area, a significant part of the eastern limb of BK belt belongs to youngest Iron Ore Group of Odisha. The lithoassemblage of this youngest Iron ore belt has suffered low grade or no metamorphism. The rocks of the study area show the general trend in NNE direction having low plunge. The structure of the rock of this area is complicated due to several fold movements. The axis of the major fold runs along N-S direction plunging due south and north. Specifically the Langalota ore body, the northern part plunges due north and southern part plunges due south.

The structural disposition and pattern of the study area consist of three distinct types of folds, which represent deformation history of the area and individual geometric dissimilarity. The earliest fold is the first-generation (F_1) structure, which is found to be open upright folds of symmetric or asymmetric nature with NS striking axial planes. The second phases of folds (F_2) with axial planes striking in E-W direction consist of tight isoclinal folds, which are horizontal or overturned. The third folds (F_3) comprise of more open folds with broad warps and congruous with the first folds. The area encounters random faults of various dimensions trending in E-W direction.

Rocks are subjected to polyphase deformation with maximum of three phases of folding. Interference patterns produced by successive phases of deformation are well observed. This results in forming more open type cross folding, which develops wide spread dome and basin patterns, eyed folds, hook shaped folds and mirror image folds.

Minor folds are found to be prolific in BIF where as refolded folds are relatively scarce. Minor folds of second and third phases have mostly developed where the bedding had originally planar attitude. In multi generation fold structures, often later folds affect only one limb of an early fold. The authors attribute this to the dominant flexural mechanism of folding and the difficulty of folding of non-parallel planes by buckling (Ramsay, 1967).

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