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Deformation Mechanisms and Polyphased Tectonic Evolution of the Kan Granito-Gneissic Complex (Côte d'Ivoire): Implications for the Eburnean Orogeny in the West African Craton

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Abstract

The Kan granito-gneissic complex in central Côte d'Ivoire records a polyphased tectonic evolution that reflects the progressive deformation of the Paleoproterozoic crust within the West African Craton. Detailed structural analysis reveals a spectrum of deformation mechanisms, ranging from ductile flattening, constriction, simple shear, and rotation to brittle shear and extension. These mechanisms are expressed through foliations, folds, stretching lineations, shear bands, porphyroclasts, boudinage, crenulation cleavage, fractures, and quartz veins. Four tectonic phases are identified: D1 (WNW–ESE compression) generated NS to NNE–SSW foliations and sinistral shear zones; D2 (EW compression) produced NE–SW dextral and ESE–WSW sinistral shear zones; D3 (NNE–SSW shortening) is marked by N110° crenulation cleavage and reactivation of earlier structures; and D4 (post-Eburnean brittle reactivation) is characterized by dextral and sinistral fractures and extensional quartz veins. These phases correlate with regional deformation events across the Man-Leo shield and align with the broader Eburnean orogenic framework, linking Côte d'Ivoire to equivalent crustal domains in Burkina Faso, Ghana, Senegal-Mali, and the Amazon craton. The Kan complex thus serves as a key witness to the multi-stage tectonic processes that shaped the southern West African Craton during the Paleoproterozoic.

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Introduction

The Paleoproterozoic crust of Côte d'Ivoire, part of the southern West African Craton (WAC), represents a key segment for understanding the tectono-metamorphic evolution of the Baoulé-Mossi domain. This crust is composed of volcano-sedimentary belts, metasediments, and granitoids, which together record a complex polyphased tectonic history. Among these units, the Kan granito-gneissic complex occupies a central position between the Toumodi–Fètèkro volcano-sedimentary belt to the east and the Comoé metasediments to the west. Its lithological diversity—migmatitic gneisses, mylonitic gneisses, and basic intrusions—makes it a privileged site for investigating deformation mechanisms and tectonic phases within the Eburnean orogeny. Despite its importance, the structural evolution of the Kan complex remains insufficiently documented. Early studies emphasized its correlation with the Dabakala gneisses and suggested a Burkinian substratum (Mortimer, 1990, 1992; Lemoine, 1988). Later work challenged this interpretation, proposing instead that the Kan complex represents a syntectonic granitoid emplaced within a transcurrent system (Daouda, 1998). While these contributions clarified aspects of its geological setting, they left unresolved questions regarding the detailed deformation mechanisms and the succession of tectonic phases.

The earliest deformation phase (D1) is attributed to collisional tectonics around 2.1 Ga, which contributed to the cratonization of terranes surrounding the Archean nuclei. During this stage, the Proterozoic crust was thrust against the Archean basement, marking the onset of the Eburnean orogeny (Feybesse *et al.,* 1989). Subsequent phases (D2 and D3) correspond to major transcurrent tectonics, involving sinistral and dextral strike-slip shear zones that affected the entire Birimian series (Milési *et al.,* 1992). These events imposed new compressive regimes and reactivated earlier structures, producing a complex polyphased tectonic fabric. Regional studies across the southern West African Craton have further highlighted the diversity of deformation events. Early collisional phases (2160–2120 Ma) are often associated with N–S oriented compression or extension, while later events (2120–2070 Ma) are dominated by NW–SE compression (Grenholm *et al.,* 2019).

Investigations in Burkina Faso, Senegal, Guinea, and Ghana have documented similar tectonic phases, emphasizing the widespread impact of the Eburnean orogeny (Baratoux *et al.,* 2011; Perrouty *et al.,* 2012; Jessell *et al.,* 2012; Lebrun *et al.,* 2017; Dabo *et al.,* 2018). Within this broader framework, the Kan granito-gneissic complex represents a crucial segment of the Proterozoic crust in Côte d'Ivoire. Its position between the Toumodi–Fètèkro volcano-sedimentary belt and the Comoé metasediments makes it a key site for examining the interplay between ductile and brittle deformation, shear zone dynamics, and crustal evolution during the Eburnean orogeny.

However, despite its significance, the detailed mechanisms of deformation and the succession of tectonic phases recorded in the Kan complex remain insufficiently explored, underscoring the need for integrated structural analyses. More broadly, research across the Birimian of Côte d'Ivoire and the southern WAC has highlighted polyphase deformation events but often in a fragmented manner. For example, studies in Boundiali and Bondoukou-Tanda have documented local tectonic phases without establishing systematic correlations between granito-gneissic complexes and adjacent metasediments (Djroh *et al.,* 2022). Similarly, investigations in Ghana, Guinea, and Senegal have reported compressive and transcurrent phases linked to the Eburnean orogeny (Jessell *et al.,* 2012; Lebrun *et al.,* 2017; Dabo *et al.,* 2018), yet the integration of these findings into a coherent regional framework remains incomplete. Even within Côte d'Ivoire, major shear zones such as Brobo and Dimbokro have been recognized as fundamental tectonic features (Bi Seydou *et al.,* 2018), but their precise role in controlling deformation within the Kan complex has not been fully established.

This lack of integrated structural analysis constitutes a significant gap in the literature. While geochemical and petrogenetic studies have advanced our understanding of magmatic processes, the mesostructural record—foliations, lineations, folds, shear zones, and brittle fractures—has not been systematically analyzed in relation to regional tectonic phases. Consequently, the broader geodynamic significance of the Kan complex within the Eburnean collisional system remains underexplored.

The present study seeks to address these shortcomings by providing a comprehensive structural analysis of the Kan granito-gneissic complex. Through detailed field observations, stereographic projections, and mesostructural characterization, we aim to identify the deformation mechanisms and reconstruct the succession of tectonic phases. By situating these phases within the broader framework of the Eburnean orogeny, this work contributes to refining regional tectonic correlations across the West African Craton. Ultimately, the study enhances our understanding of the polyphased tectonic evolution of the Ivorian crust and its implications for continental-scale geodynamics.

Geological context

The geological context of Côte d'Ivoire is framed within the West African Craton (WAC), specifically the Man-Léo shield (Figure 1A), which is divided into two major domains of distinct ages separated by the Sassandra fault: the Archean Kenema-Man domain to the west and the Paleoproterozoic Baoulé-Mossi domain to the east (Bessoles, 1977). The Archean domain was structured during two major orogenic cycles: the Leonian (3.5–2.9 Ga) and the Liberian (2.9–2.6 Ga). It is characterized by high-grade metamorphic units such as granulitic gneisses, charnockites, and tonalitic-trondhjemitic gneisses, intruded by granites and basic-ultrabasic complexes (Camil, 1984; Kouamélan *et al.,* 1997). These formations record intense metamorphism and deformation, with relics dated at 3050 ± 10 Ma and 2800

± 8 Ma. The Eburnean orogeny (ca. 2.1 Ga) also left retrogressive imprints in this domain, particularly near the Sassandra fault. The Paleoproterozoic domain, which hosts the Kan granito-gneissic complex, was structured during the Eburnean megacycle (2.5–1.6 Ga). It contains Birimian-age rocks (2.5–2.1 Ga), considered an episode of juvenile crustal accretion (Abouchami *et al.,* 1990; Boher *et al.,* 1992). These formations consist of volcano-sedimentary belts generally oriented NNE–SSW, bordered or intruded by granitoids. The Birimian sequences include metavolcanic basalts, andesites, rhyolites, and associated metasediments such as turbidites and quartzites, often cut by tonalite-trondhjemite-granodiorite (TTG) batholiths and later granites. The lithostratigraphy of the Birimian has long been debated. Early models distinguished a lower volcanic unit and an upper sedimentary unit (Junner, 1940; Milési *et al.,* 1992), while later studies argued for contemporaneity, with sediments derived from volcanic sources (Hirdes *et al.,* 1996). Mapping in Côte d'Ivoire revealed that the ages of volcanic-sedimentary belts decrease progressively from southeast to northwest, suggesting diachronous accretion (Hirdes & Davis, 2002). This led to subdivision into two sub-provinces: the eastern Birimian (2190–2150 Ma) and the younger western Bandamian (~2105 Ma).

Within this Paleoproterozoic framework, the Kan granito-gneissic complex occupies a central position in Côte d'Ivoire (Figure 1B), between the Toumodi-Fètèkro volcano-sedimentary belt to the east and the Comoé basin to the west. It extends over ~100 km in length and ~20 km in width (Daouda, 1998). The complex is composed mainly of migmatitic and mylonitic gneisses, with basic intrusions and xenoliths (Figure 1C). Previous studies debated its origin: Mortimer (1990, 1992) considered it equivalent to Dabakala gneisses (Burkinian substratum), while Daouda (1998) argued it is a syntectonic granitoid emplaced within a transcurrent system. The Kan complex thus represents a key witness to the Paleoproterozoic evolution of the Man-Léo shield. Its structures and deformation patterns are consistent with the regional tectonic framework of the Baoulé-Mossi domain, shaped by the Eburnean orogeny and subsequent tectonic reactivations.

Materials and Methods

Fieldwork procedures

The investigation began with a systematic field campaign across representative outcrops of the Kan granito-gneissic complex. Particular attention was given to migmatitic and mylonitic gneisses, as well as their contact zones with adjacent volcano-sedimentary and metasedimentary formations. At each site, mesostructures such as folds, foliations, lineations, shear bands, boudins, fractures, and quartz veins were carefully described and classified according to their geometry, kinematics, and relative chronology. Structural orientations—including strike, dip, and plunge—were measured using Sylva-type compasses to ensure precision and reproducibility. To complement these measurements, high-resolution photographs were taken to document key deformation features, especially those illustrating shear sense indicators, parasitic folds, and extensional structures.

Data processing and analytical approach

Following the field campaign, all structural measurements were exported into stereonet software for quantitative analysis. This allowed the construction of directional rosettes and stereographic projections, which provided a clear visualization of the principal orientations of structures. The fabrics observed in the field were interpreted in terms of strain ellipsoid geometry, enabling the identification of deformation mechanisms. Kinematic indicators analyzed following established criteria to determine shear sense and deformation intensity. Quartz vein orientations and fracture systems were also examined to distinguish ductile from brittle regimes and to infer late-stage extensional processes affecting the complex.

Integration with regional tectonic framework

The structural data obtained from the Kan complex were then correlated with successive tectonic phases (D1–D4) and interpreted within the broader collisional and transcurrent systems of the Eburnean orogeny. This integration ensured that local deformation mechanisms were placed in their regional geodynamic context.

Comparative analysis was undertaken with published structural studies from adjacent domains of the Man-Leo shield and other segments of the West African Craton (Baratoux, *et al.,* 2024).

This approach allowed the Kan granito-gneissic complex to be understood not only as a local manifestation of polyphased deformation but also as a key element in the accretionary and collisional processes that shaped the Paleoproterozoic crust during the Eburnean orogeny.

Results and Discussion

Folds and fabrics

The Kan granito-gneissic complex is strongly affected by ductile deformation, expressed through diverse fold geometries and foliations. Subhorizontal folds are widespread in migmatitic gneisses, particularly affecting leucosome veins, with vertical axial planes and shallow plunges of 5–10°S (Figure 2A). Intrafoliar folds of "S" and "Z" types mark sinistral and dextral shearing respectively (Figure 2B,C), while rootless folds indicate high-intensity shear (Figure 2D). Symmetrical major folds host parasitic structures, including "Z," "S," and "M" folds, in their limbs and hinge zones (Figure 2E).

Foliation is well developed, alternating quartzo-feldspathic and ferromagnesian bands, dipping subvertically around 70°E (Figure 3A). This foliation carries shallow mineral lineations (Figure 3B), producing an "SL" fabric that reflects simple shear deformation. Stretching lineations, expressed in quartz, feldspar, amphibole, micas, and xenoliths, are prominent in mylonitic gneisses, classifying them as L-tectonites (Figure 3C,D,E). Flattened xenoliths in the XZ plane of the strain ellipsoid further confirm constrictional deformation (Figure 3F).

Shear zones and kinematic indicators

Shearing is pervasive across the complex, with five principal shear band orientations identified: N10°, N170°, N50°, N90°, and N110° (Figure 4A, B, C, E). Sinistral shear dominates along N10°, N170°, and N110°, while dextral shear is expressed along N50° and N90°. The N170° shear band is particularly abundant and coincides with the orientation of S/C structures, where the S-plane (N10°) parallels foliation and the C-plane (N170°) records sinistral displacement (Figure 4F).

These structures consistently carry subhorizontal mineral lineations, reinforcing their association with ductile transcurrent shearing. Kinematic indicators such as delta-type porphyroclasts with monoclinic symmetry (Figure 5A) serve as reliable markers of NS to NNE–SSW sinistral shearing. Boudinage is also common, with shearband boudins showing antithetic movements relative to the general shear sense, while symmetrical boudins align with foliation and lineation. Later compressive phases are recorded by crenulation cleavage oriented N110°, produced by microfolding of earlier foliation (Figure 5B).

Brittle deformation and extensional features

Superimposed on ductile fabrics, brittle deformation is expressed through fractures, quartz veins, and extensional structures. Fracturing is most intense in mylonitic gneisses at the eastern margin of the complex, particularly near Laourébo and the N'zi River, with EW and NW–SE shear fractures producing dextral displacements (Figure 6). Quartz veins occur predominantly in NS orientations, parallel to foliation, dipping 60–70°E, and act as markers of NS to NNE–SSW extension (Figure 6). A secondary set of EW-oriented veins produces dextral displacements.

Extensional fractures are especially well developed near the Comoé basin, with two distinct families: N080–N100° fractures with oblique quartz fibers (Figure 5D), and N120–N130° fractures associated with pull-apart systems (Figure 5C). These features collectively indicate late-stage brittle extension linked to EW compression and post-Eburnean tectonic adjustments.

Deformation mechanisms and associated tectonic events

The Kan granito-gneissic complex records a diverse set of deformation mechanisms that reflect the polyphased tectonic evolution of the Paleoproterozoic crust in Côte d'Ivoire. Flattening is expressed by NS to NNE–SSW foliations parallel to axial planes of folds, as well as by the vertical axial planes of symmetrical folds with shallow plunges (Figure 2A). This flattening is linked to WNW–ESE shortening, which also produced constrictional deformation, evidenced by mineral stretching lineations and the flattening of basic xenoliths in the XZ plane of the strain ellipsoid (Figure 3F). Simple shear is manifested in intrafoliar folds, parasitic structures, and the SL fabrics of migmatitic gneisses (Figure 3A, B), while rotational deformation is highlighted by delta-type porphyroclasts (Figure 5A) and rootless folds (Figure 2D), both of which indicate high-intensity shearing. The dominant shearing direction is globally NS, expressed in N170° and N10° sinistral shear bands and S/C structures (Figure 4F). These features suggest that the Kan complex belongs to a major sinistral NS transcurrent shear zone, interpreted as an extension of the Brobo shear zone described in northern Côte d'Ivoire (Gasquet *et al.,* 2003). Additional shear zones oriented N110° (sinistral) and N50°–N90° (dextral) further illustrate the complexity of strain partitioning.

Figure.1 A: Geological sketch map of the Man-Leo shield (modified from the BRGM SIGAfrique map, Milési *et al.*, 2004) with location of the study area; B: Geological sketch map of Côte d'Ivoire, (Kouamelan, 1996) locating the study area; C: Carte géologique du complexe granito-gneissique du Kan

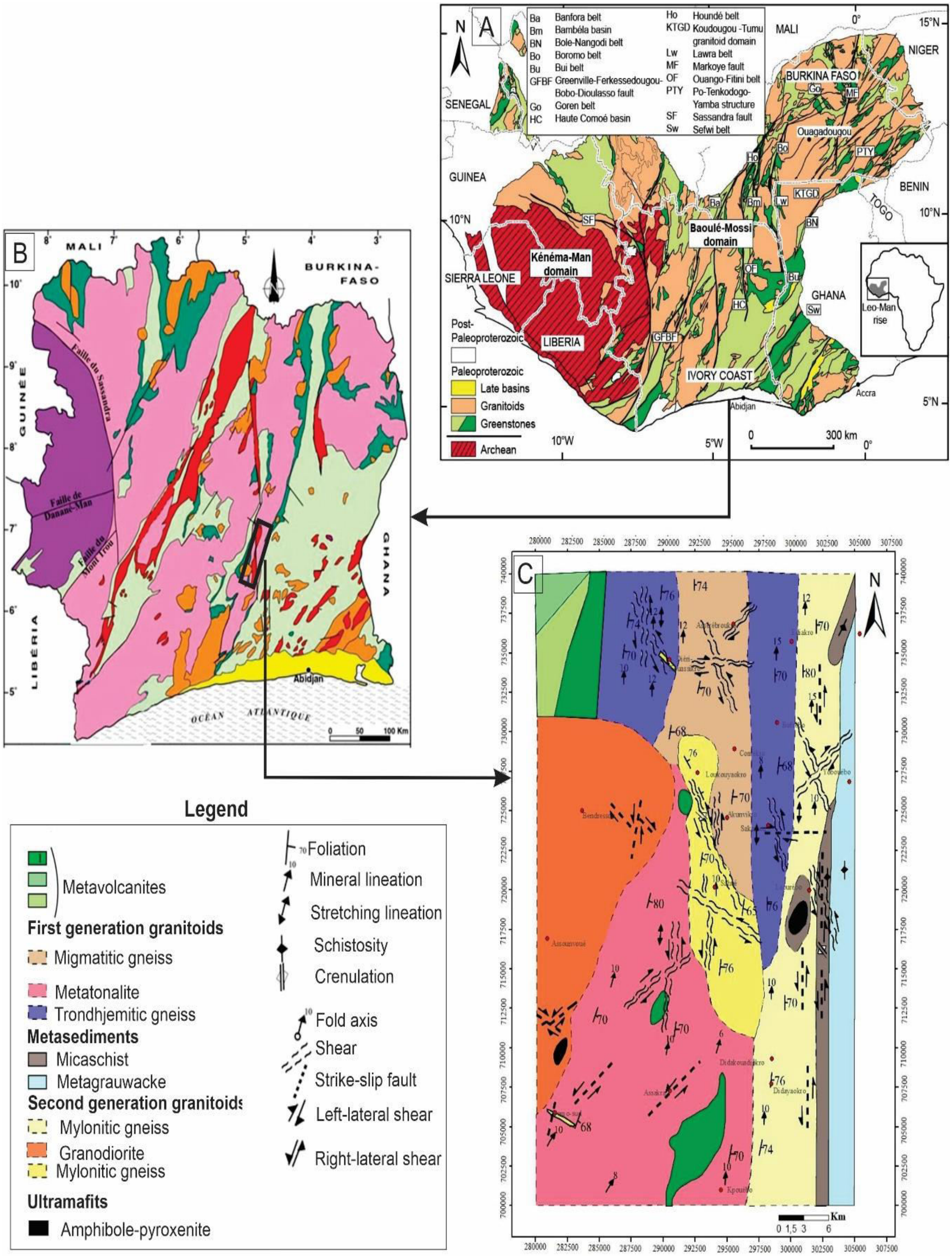


Figure.2 Photograph of folds at outcrop scale in the gneissic rocks. A: Folds with subhorizontal axes; B: Similar folds; C: Symmetrical major folds with parasitic Z, S and M folds sitting respectively in the left limb, right limb and in the hinge. Note foliation parallel to axial plane; D: Intrafoliar ‘’S’’ folds and rootless fold; E: intrafoliar "Z" fold.

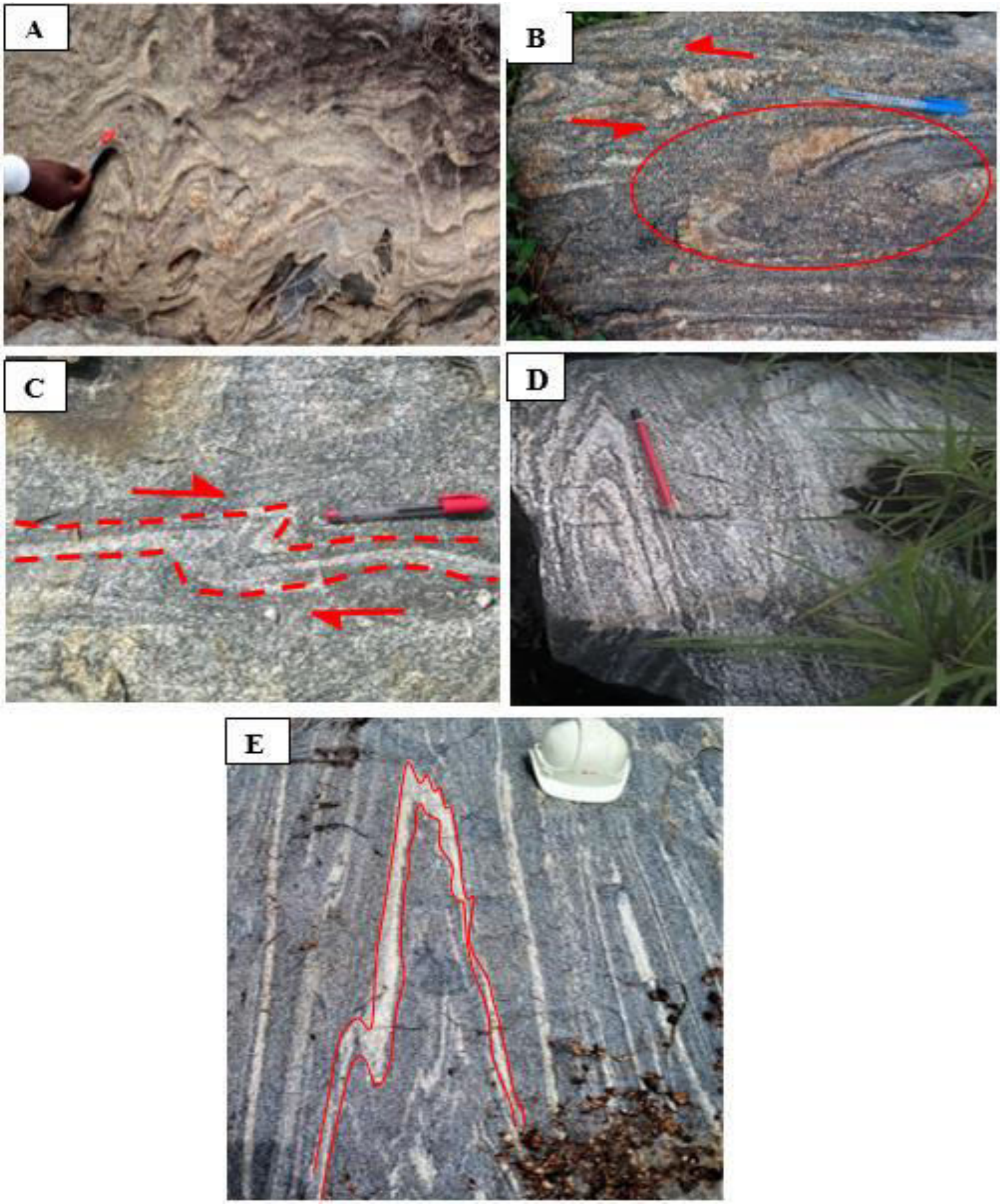
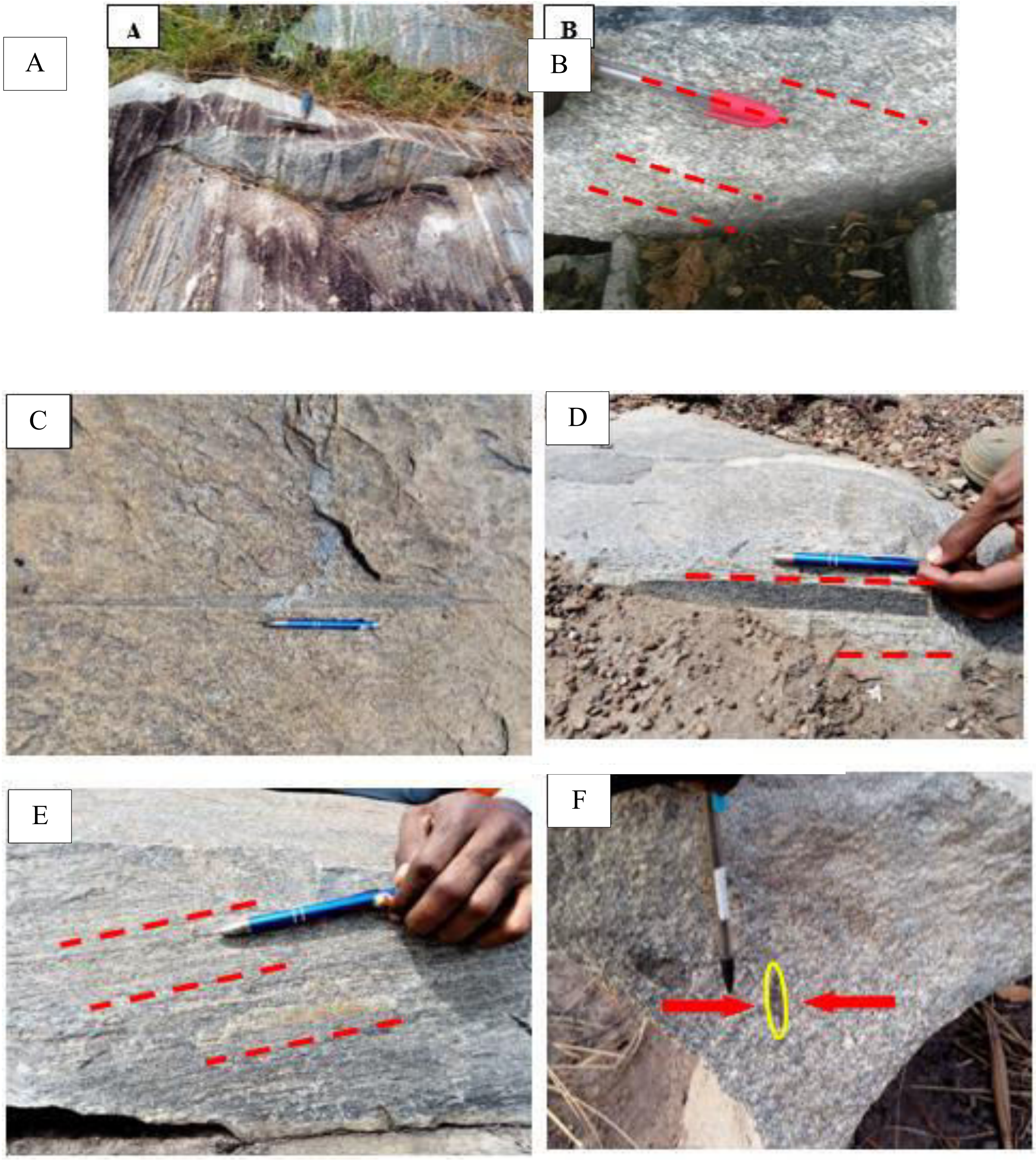


Figure.3 Photograph showing subvertical foliation (A), with subhorizontal mineral lineation in migmatitic gneiss (B), and stretching lineations in the gneissic rocks (C); D: Stretching of basic xenolith; E: Stretching lineation showing subhorizontal plunge; F: Basic xenolith showing deformation by flattening in XZ plane of strain ellipsoid.



Figures.4 Photograph of the main shear bands directions in the granito-gneissic complex of Kan A: NS Sinistral shear band; B: N170° sinistral shear band; C: N110° sinistral shear band; D: N50° dextral shear band. E: N90° dextral shear band; F: S/C structure with S and C planes respectively oriented N10° and N170°.

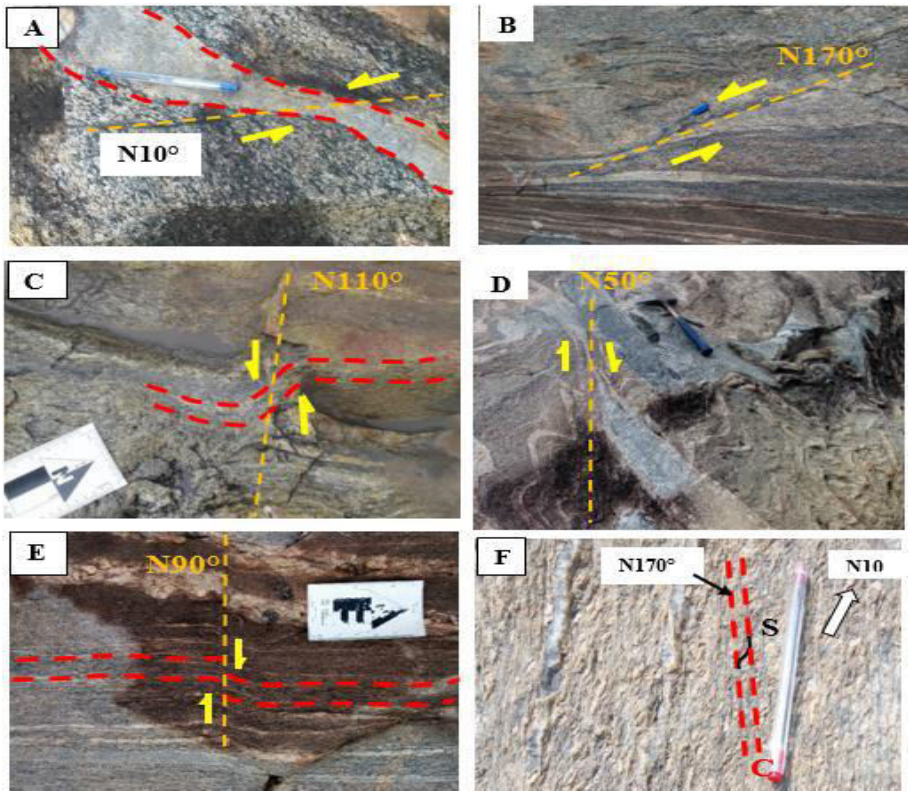


Figure.5 Field photography showing A: delta (δ) type porphyroclast showing sinistral shearing and B: crenulation cleavage; C: EW extensional fractures and NW-SE extensional fractures; D: EW Extensional fractures with oblique quartz fibers.

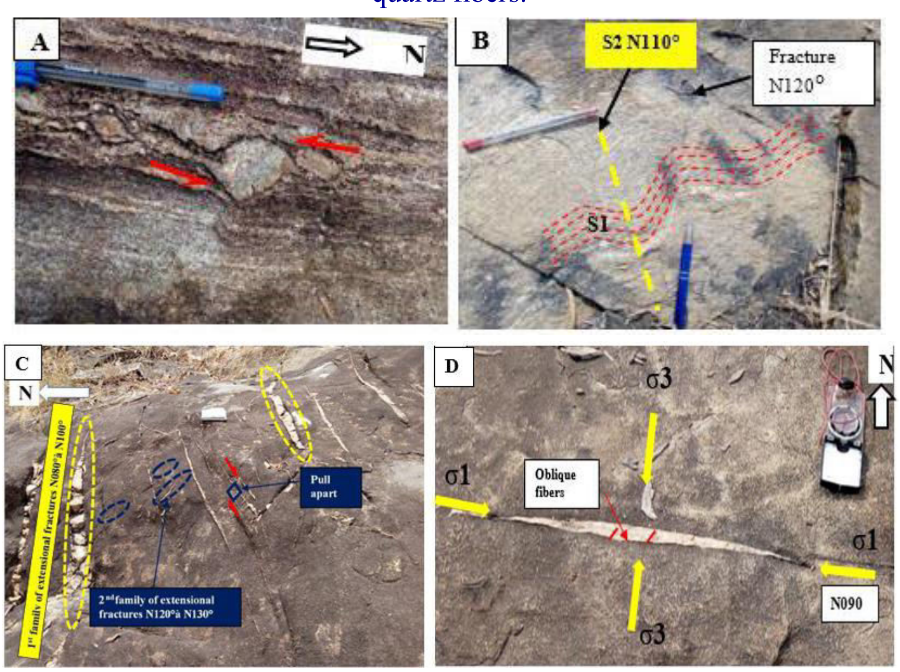


Figure.6 Stereographic projections showing the orientations of measured structured throughout the study area

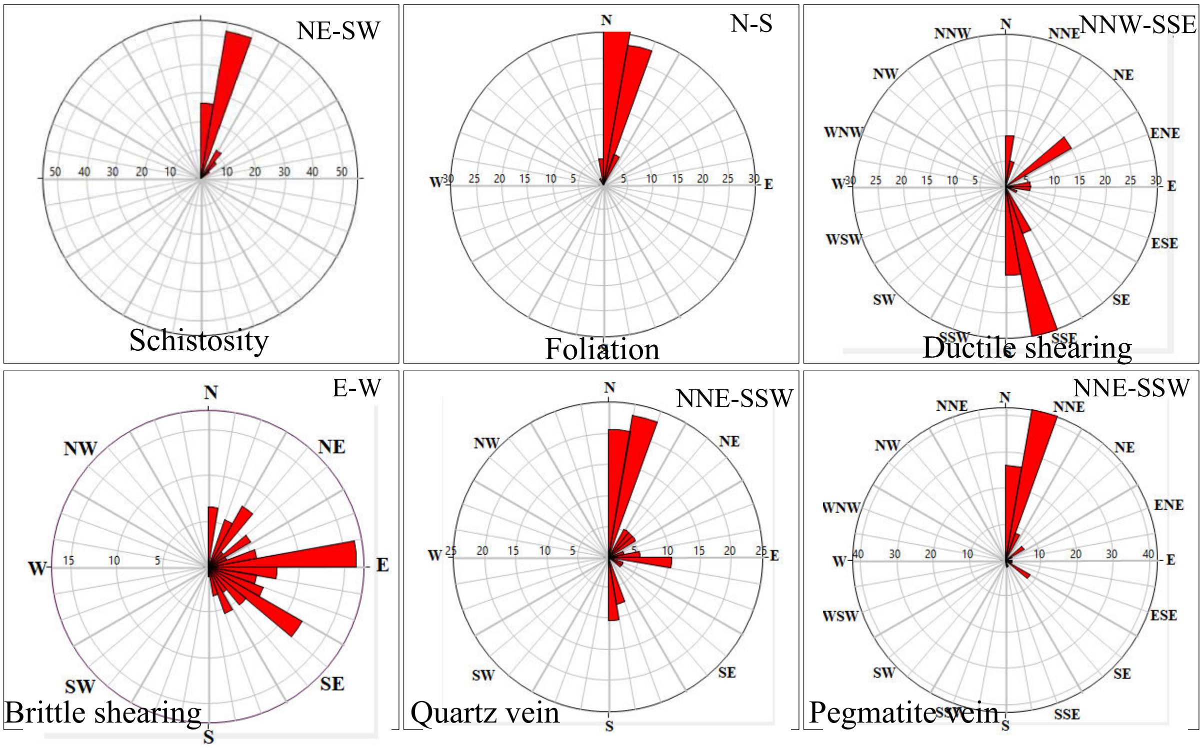
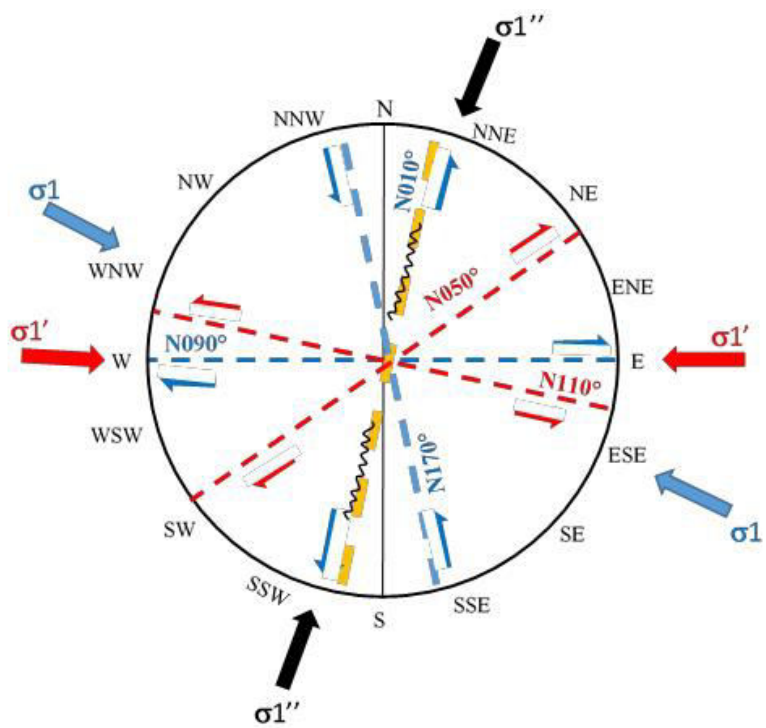


Figure.7 Sketch showing the orientation of principal stress axes (σ_1) and associated shear zones during deformation of the granito-gneissic complex of Kan. The blue dashed line denotes sinistral σ_1 stress axes and shear zone directions formed during D1 compression, while the yellow dashed line indicates the foliation trend. The red dashed line represents sinistral σ_1 stress axes and shear zone orientations generated during D2 compression. Finally, the black sigmoidal line illustrates the crenulation cleavage developed during D3 compression.



Intrafoliar "Z" folds, though less common, may represent either simultaneous simple shear deformation or later tectonic phases associated with NE–SW to NNE–SSW shortening. This shortening is consistent with the formation of N110° crenulation cleavage (Figure 5B), which likely corresponds to reactivation of earlier weak zones such as the N'Zi shear zone (Bard, 1974). Brittle shear is superimposed on ductile fabrics, with fractures, quartz veins, and extensional structures marking the transition to late-stage deformation. Extensional fractures with oblique quartz fibers (Figure 5D) indicate opening oblique to the extension direction, while pull-apart systems oriented N120°–N130° (Figure 5C) reflect EW compression. Dextral fractures with EW, NW–SE, and NE–SE orientations, together with NS sinistral fractures (Figure 6), represent the final brittle overprint.

Collectively, these mechanisms demonstrate a progressive evolution from ductile flattening and shear to brittle extension, consistent with deformation models for the Birimian crust of the West African Craton (Passchier & Trouw, 2005; Mattauer, 1980; Vidal *et al.,* 1996).

Tectonic phases

The deformation mechanisms described above correspond to four tectonic phases (D1, D2, D3 and D4), each reflecting distinct stress regimes. D1, D2 and D3 can be related to different compressions corresponding to different positions of the principal stress ($\sigma 1$) (Figure 7). D1 is associated with WNW–ESE compression, producing NS to NNE–SSW foliations, stretching lineations, folds with subhorizontal axes, and sinistral shear zones (N170° and N10°), accompanied by EW dextral shear zones (Figure 4). D2 corresponds to EW compression, marked by NE–SW dextral shear zones (N50°) and ESE–WSW sinistral shear zones (N110°). D3 reflects NNE–SSW compression, expressed by N110° crenulation cleavage (Figure 9B), and indicates reactivation of earlier shear zones under new stress conditions. Finally, D4 represents brittle deformation, with EW, NW–SE, NE–SE dextral fractures and NS sinistral fractures (Figure 6), interpreted as post-Eburnean tectonic adjustments. These phases correlate with regional deformation episodes documented in the Birimian orogenic belt, where early events (2160–2120 Ma) are linked to N–S compression, and later events (2120–2070 Ma) to NW–SE compression (Grenholm *et al.,* 2019). Similar polyphased deformation has been reported in Burkina Faso (Lompo, 1991), Senegal-Mali (Ledru *et al.,* 1989), and Ghana (Jessell *et al.,* 2012), confirming that the Kan complex records the same collisional and transcurrent tectonic systems that characterize the Eburnean orogeny.

Regional implications

The deformation history of the Kan granito-gneissic complex situates Côte d'Ivoire within the broader framework of the Eburnean orogeny, a collisional event that shaped the Paleoproterozoic crust of the West African Craton. The NS sinistral shear zones observed in Kan are consistent with major transcurrent structures such as the Brobo shear zone in northern Côte d'Ivoire (Gasquet *et al.,* 2003) and the Sassandra fault (Bard, 1974), highlighting the continuity of transcurrent tectonics across the Man-Leo shield. The D1 and D2 phases correspond to regional collisional systems documented in Burkina Faso and Senegal-Mali (Ledru *et al.,* 1989; Baratoux *et al.,* 2011), while D3 reflects NNE–SSW shortening comparable to deformation in the Sefwi series of Ghana and the Mako belt of Senegal (Jessell *et al.,* 2012; Dabo *et al.,* 2018). The brittle D4 phase, marked by extensional fractures and quartz veins, indicates post-Eburnean reactivation, consistent with late tectonic adjustments reported in Guinea and Ghana (Lebrun *et al.,* 2017; McFarlane *et al.,* 2017). Thus, the Kan complex provides a key record of polyphased deformation, situating Côte d'Ivoire within the accretionary-collisional system that extends across the West African Craton and links to equivalent crustal domains in the Amazon craton. Its structural evolution highlights the interplay between ductile and brittle regimes, confirming that the Eburnean orogeny was not a single event but a prolonged, multi-stage tectonic process that shaped the geodynamic architecture of West Africa.

In conclusion, the Kan granito-gneissic complex preserves a polyphased tectonic history that reflects the interplay of ductile and brittle deformation mechanisms within the Paleoproterozoic crust of Côte d'Ivoire. Flattening and constriction are expressed through NS to NNE–SSW foliations, subhorizontal folds, and mineral stretching lineations, while simple shear and rotation are recorded in intrafoliar folds, parasitic structures, S/C fabrics, and delta-type porphyroclasts that mark sinistral transcurrent movement. These ductile features are complemented by boudinage and crenulation cleavage, which highlight successive compressive phases and reactivation of earlier shear zones. Brittle deformation overprints the ductile regime, with EW, NW–SE, and NE–SE fractures, quartz veins, and extensional structures indicating late-stage tectonic adjustments. Together, these mechanisms define four tectonic phases: D1

(WNW–ESE compression), D2 (EW compression), D3 (NNE–SSW shortening), and D4 (post-Eburnean brittle reactivation). Regionally, the Kan complex correlates with major shear zones such as the Brobo and Sassandra faults in Côte d'Ivoire and with deformation events documented in Burkina Faso, Senegal-Mali, Ghana, and Guinea, situating it firmly within the collisional and transcurrent systems of the Eburnean orogeny. This evolution confirms that the Eburnean was not a single event but a prolonged, multi-stage tectonic process that integrated Côte d'Ivoire into the wider geodynamic framework of the West African Craton and linked it to equivalent crustal domains in the Amazon craton.

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