

Boudin Types, Their Morphology and Significance in Interpreting Deformational History in Proterozoic Rocks of North Delhi Fold Belt, North Western India

Rajendra Kumar Sharma

Director (Retired), GSI, A-55, Anand Vihar Jagatpura, Jaipur, India

Email: rajsuman87@gmail.com

How to cite this paper: Sharma, R.K. (2022) Boudin Types, Their Morphology and Significance in Interpreting Deformational History in Proterozoic Rocks of North Delhi Fold Belt, North Western India. *Open Journal of Geology*, 12, 739-754.
<https://doi.org/10.4236/ojg.2022.1210035>

Received: August 22, 2022

Accepted: October 23, 2022

Published: October 26, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The boudins can be of symmetric as well as asymmetric type and can help in determining shear sense and help unfold the deformational history, hence are important structure for recognizing the history of deformation in an area; Once the rocks of an area undergo polyphase of deformation, the boudins get modified and can no longer help in determining the deformational evidences. The present study involves identification of various types of boudins their classification and morphology as per existing status of knowledge and their role in determining the type of deformation in Neem Ka Thana belt, Proterozoic rocks of North Delhi fold belt. The study of symmetric, asymmetric and modified boudins in the area enabled the author to deduce that the rocks in above belt have suffered a polyphase deformation marked with flattening type of progressive deformation during the first phase (DF1) of deformation and the second phase (DF2) with a time gap, has produced modified boudins and folded boudin structures with the largely same axis of deformation in both these deformations.

Keywords

Boudins, Polyphase, Shearing, Neem Ka Thana Belt, Northwest India

1. Introduction

The Neem ka thana area, Sikar District, Rajasthan, exposes proterozoic sediments of Delhi Supergroup of rocks predominantly composed of marls (**Figure 1**), with some quartzites and banded calcareous semipelites pertaining to Ajabgarh group and a thick arenaceous sequence of Alwar Group characterized by

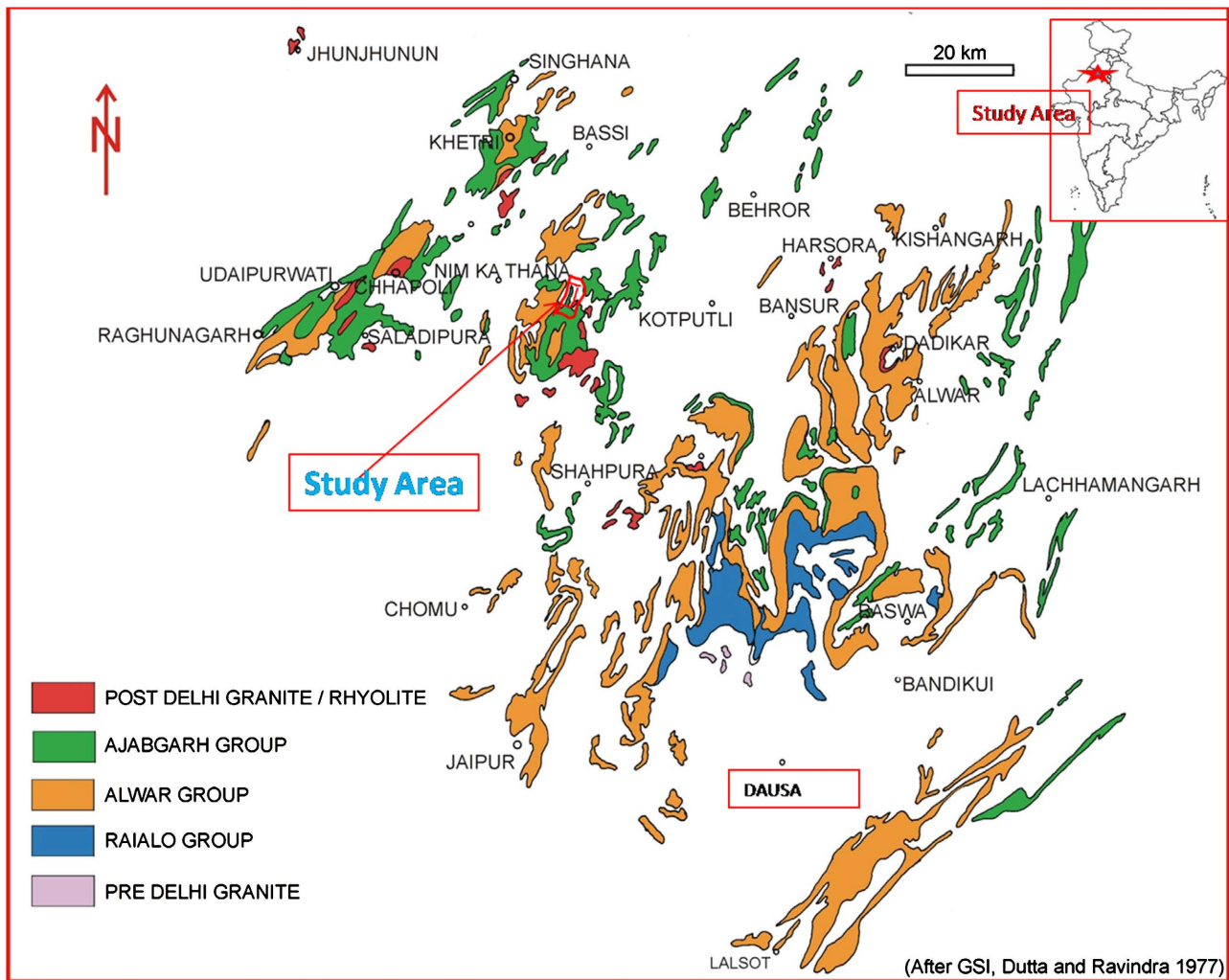


Figure 1. Geological map of the North Delhi fold belt, depicting the location of study area.

brecciated and ferruginised quartzites with occasional pebbly horizons within it. The whole sequence has been folded into map scale antiform and synforms pertaining to the second deformation. The evidences of first deformation are also recorded in terms of root less tight to isoclinal folds [1]. The third deformation, as expected, is feeble and has only been demonstrated in terms of disjunctive cleavage and some sympathetic mesoscopic slips along east west direction [2]. Besides usual planner elements of structure like bedding and schistosity, the area exposes a variety of features indicative of intense shearing of the rocks. The shearing has accompanied first deformation as well as the second. Evidences of the same are clearly recognizable in the area. The shearing is demonstrated in variety of features like stretching of grains and minerals like scapolite [3] [4], brecciation of more competent rocks like quartzite, development of pinch and swell structures, limb shears, grain rotation, developments of sigmoids, dragging of rocks, tension gashes filled and open, and to top the above all features a large variety of boudins [5] [6]. The present topic of discussion will be types of boudings and their significance in determining the type and degree of shearing.

Boudinage is a very common structure which helps the geologist understand “who is stronger than who?” and helps them guess the physical conditions at which deformation took place. The term boudin was first used in 1908 [7] for shortened boudin or mullions in Bastogne in Belgium. The exact definition and meaning of the terms boudin and boudinage have changed through much of the twentieth century, but there is now consensus that boudins are extensional structures formed by layer-parallel extension, while boudinage is the process that leads to the formation of boudins from originally continuous layers [8].

Boudin structures were first described and named [7] [9]. The large varieties that occur in nature have been the subject of considerable study [10]-[29]. Classic boudins form where single competent layers are extended into separate pieces through plastic, brittle or a combination of plastic and brittle deformation mechanisms. The boudin aged layer is located in a rock matrix that deforms plastically. Boudins are separated by brittle extension fractures or by shear fractures that may be symmetric or asymmetric; instead of fractures, boudins may also be separated by narrow ductile shear zones that are confined to the boudinaged layer [30]. Boudinage style can also vary enormously, as the eye-shaped boudins are called “pinch-and-swell” structures. Indeed, when boudins are not entirely separated and are connected by a very thin layer, as if they were “pinched” by a finger. These structures suggest that both the boudinated layer and the surrounding rocks are deforming in a ductile way. [30] proposed different types of boudin geometry, involving extensional fracturing; a) rectangular boudin, b) barrel shaped boudin, c) fish mouth boudin, d) unicorn boudin [31]. Classified boudins kinematic classes are: 1) symmetrical boudins, which do not experience slip on the inter-boudin surface, forming by no-slip boudinage, and 2) asymmetrical classes with slip on the inter-boudin surface: synthetic slip boudinage (S-slip) and antithetic slip boudinage (A-slip) with respect to bulk shear sense.

No consistent nomenclature for boudin structural elements or geometric parameters has been adopted in the literature, even for the simplest system of symmetric boudinage [14] [32]-[39]. Considering a suite of nomenclature for structural elements and geometric parameters that uniquely describes all possible boudin structures is adopted. The structures including: 1) Object boudin. boudinage of a competent object of limited dimensional extent such as a mineral grains termed as 2) Single-layer boudinage of a competent layer in a less competent host, 3) Multiple layer boudinage: a packet of thin competent layers, a variation of this “composite boudins” composed of boudinaged sub-layers within a boudinaged packet of layers, giving Nested boudins of different scale, 4) Foliation boudinage, of a foliated rock devoid of, or irrespective of, layers of differing competence were described [36] [37], End member boudin block geometries by considering all kinematic and geometric criteria, Goscombe *et al.* 2004, have suggested a detailed classification and the same has been followed for the purpose of present study to name the different types of boudins recorded from the

studied area.

2. The Observations from the Study Area and Interpretations There of

Boudins come in different shapes depending on how they behaved during deformation. The different shapes relate to the competence contrast across the boudinaged layer and of the type of fracture that forms extension or shear fractures [38]. Rectangular shaped boudins form when they are not deformed internally, when the boudinaged layer behaves completely stiff or brittle. Barrel-shaped and fish-mouth boudins result, when the boudins deform plastically along their margins. Asymmetrical boudins can be used as a shear sense indicator if they have orientation. Boudins develop significantly in pure shear alone; can also bring asymmetry of initially squarish clasts if embedded in a matrix of considerably different viscosity [39] [40]. Symmetry of boudinaged clasts too depends on competency contrast between the matrix and clast in some cases, and on the degrees of slip of inter-boudin surfaces and pure shear [41]. Generally, the boudins in the Neem ka thana belt are non oriented, symmetrical, and modified and complex structures [42] [43], hence do not help as direct shear sense indicators, and comparable with the bulk shear sense. However few instances of conjugate shears depicting both dextral and sinistral sense of shearing have been observed. Despite being symmetrical in nature, significant information on type of shearing and episodes of shearing has been obtained from the boudin structures of the belt. The Proterozoic rocks in parts of Neem Ka thana comprise a marly sequence providing an ideal sequence for boudinaging, as there is a competence contrast in carbonate, semipelitic and quartzite. The shearing evidences are recorded in terms of stretching, pinch and swell, limb shears, attenuated limbs and ductile flow of the material [43]. The boudins are developed all through the belt at different stratigraphic levels and in different lithologies. The various types of boudins recognized and studied in the belt are listed under using the classification proposed by [35], 1) Torn boudins. 2) Chocolate tablet boudins. 3) Drawn boudins. 4) Necked boudins and pinch and swell structure. 5) Tapering boudins. 6) Fish mouth boudins. 7) Shear band type boudins and 8) Modified boudins.

2.1. Torn Boudins

This type of boudins develops generally in the competent rock where the shear along the extension direction is maximum and the component of shear orthogonal to maximum shear plane is small. Rhombic or square fragments of the rock result under extension/shear, with these fragments having no sense of rotation and hence symmetric. Such features have been recorded from the Ajabgarh quartzite in the area, which are single layer as well as multilayer torn boudins. (Figure 2(a) & Figure 2(d)). Here in the Figure 2(a) the ferruginised quartzite rock unit has produced torn boudins of the elongated block type, some of

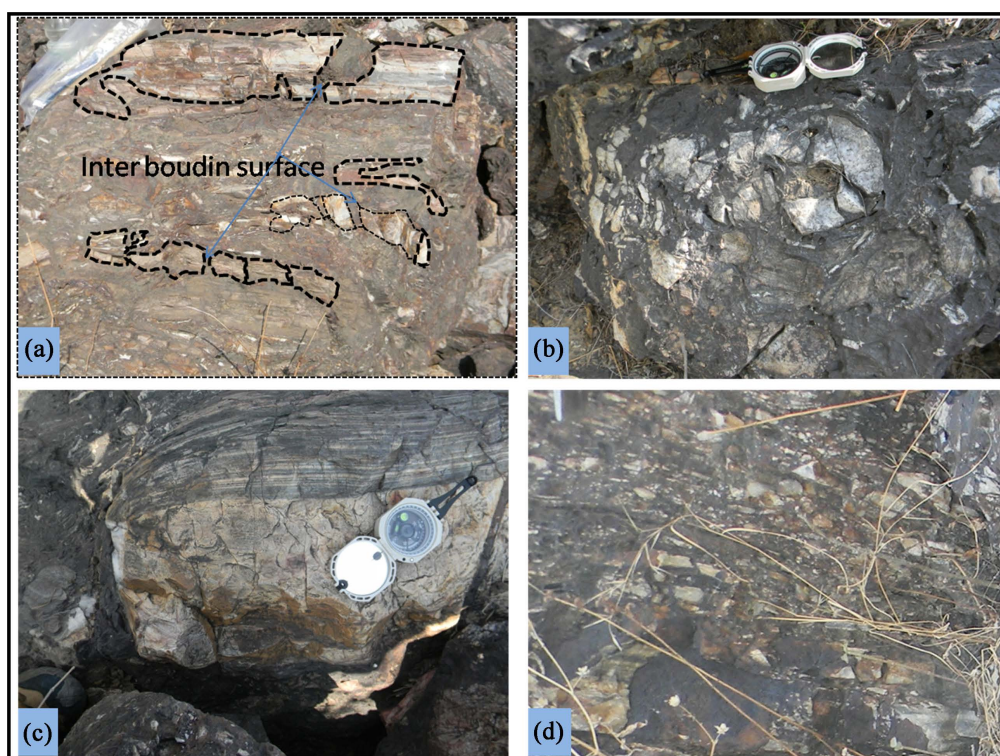


Figure 2. Shearing evidences and types of boudins from east of Gursali ki Dhni area, Neem ka Thana belt. (a) Brittle shearing involving multilayer boudinaging producing predominantly torn boudins, besides folded boudins; this suggests more than one episodes of shearing. (b) Quartzite layer enclosed within the ferruginous mass producing torn boudins, subsequently folded during post shearing deformation, suggesting at least two deformation episodes. (c) Huge Quartzite boulder occurring as boudin, exhibiting swerving of carbonaceous phyllite rock around it which acts as inter-boudin surface and exhibits foliation which is folded. (d) Torn boudins of different size involving multiple layers.

which are necked without any sense of rotation while some are folded. The multilayer torn boudins in **Figure 2(b)** have been folded. This is difficult to decipher whether the rock was folded first and boudinaged latter or vice versa. The progressive continued shearing involves folding and then boudinaging [36]. This means that during continuous deformation, a layer may be first shortened and possibly folded, and then boudinaged, but NOT first boudinaged and then folded [44]. For this reason, if shortened boudins are found, this is evidence for either an unusual flow type without rotating flows, like in an eddy, or that deformation is polyphase, with a change in the orientation of principal shortening directions between periods of deformation [44]. In practice, it may not be possible or useful to determine exactly what combination of deformation was involved in the formation of a modified boudin structure. However, in all cases it is useful to know that such overprints exist, since they indicate a change in the nature of deformation in an area [36]. In the present case, it is important to decipher whether the formation of boudin and folding of the same is the result of same progressive deformation or it involved multiple generation of deformation.

Some modified boudins are straight forward to recognize, but others may closely resemble simple single-phase boudins. In all cases, crucial information is

stored in both the inter boudin zone and any enveloping foliations present along the boudin exterior. In reworked boudin structures, this includes shortening or folding of inter-boudin vein infill, or solution or crenulation cleavage development in the inter-boudin zone or over the boudin exterior [35], **Figure 2(b)** clearly demonstrates folding of the boudin and also the enveloping surface which is carbonaceous phyllite here, exhibiting swerving around of the boudin block by enveloping surface (**Figure 2(c)**), and ferruginous material as matrix has filled the inter boudin space and minor quartz veins in inter boudin surface appear folded (**Figure 2(a)**). These features might suggest these modified structures to be product of multiple deformation events.

2.2. Drawn Boudin

Drawn Boudin is the another common structure found in the area and mostly preserved in the quartzitic/sandy partings within the carbonate, besides symmetrical non oriented fragments of vein quartz, called drawn boudins. In fact the features exhibited in **Figure 3(a)** and **Figure 3(b)** depict a transition between the torn and drawn boudin, the quartz vein boudin in **Figure 3(a)** has under gone some rotation but is nonindicative, while the host has yielded under ductile

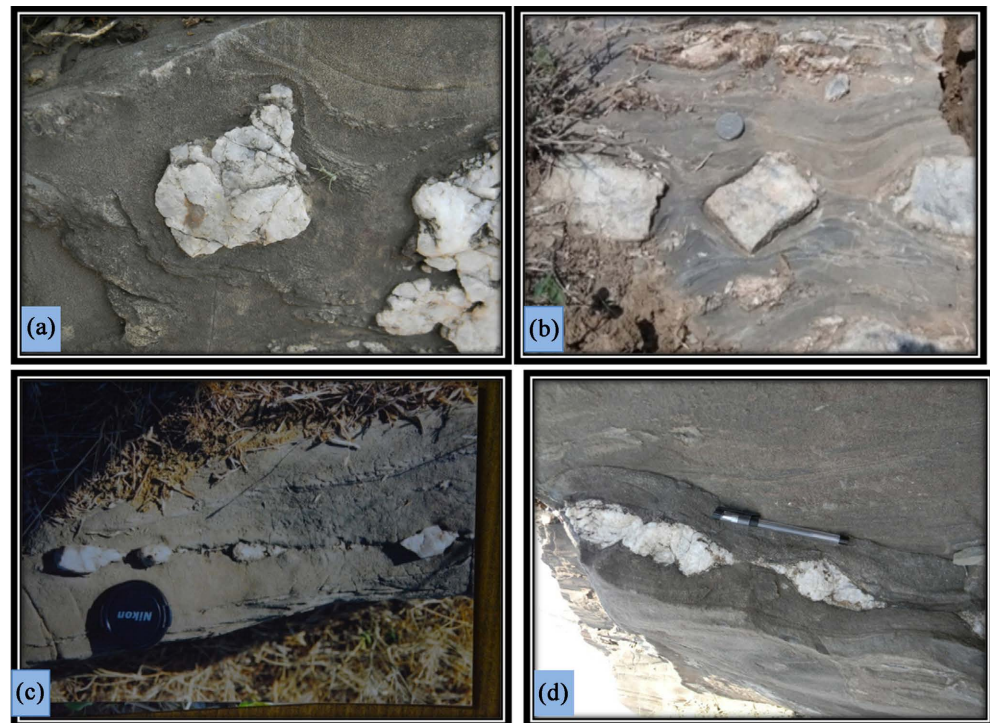


Figure 3. Various types of boudins from Dariba and Kharagbinjpur area, Neem ka Thana belt [6]. (a) Asymmetric drawn boudins without rotation. Note the plastic deformation of matrix/enveloping surface. (b) Chocolate tablet boudins. Note the inter-boudin surface (Sib) occupied by plastically deformed matrix, exhibiting flowage/folding of the enveloping surface, case of large competence contrast between boudin and host. (c) Quartz vein within dolomite Pinch and swell structure, with boudins barely connected, leading to development of necked boudin. (d) Quartz vein with in dolomite producing Pinch and swell structure with large aspect ratio (L/W) and curvilinear, parallel Se (boudin exterior).

deformation due to low competence and shows folding. The progressive shearing here caused the carbonate host get folded and the quartz vein block to undergo certain rotation after being torn in to boudins. **Figure 3(b)** also depicts a sort of torn boudin with its faces parallel to each other and no rotation. The chocolate tablets boudins can form by two sets of extension fractures, one parallel and other perpendicular to the lineated rock [44] are produced due to significant difference between the stress along and orthogonal to the linear surface/foliation. Here it can be inferred that initially the extension along the linear plane was more than along the axis orthogonal to it, causing fracturing of the quartzitic material by extension but as the deformation continued there appears to be change in the stress component orthogonal to the foliation/linear plane causing the rotation of the block and folding of the enveloping surface due to ductile yielding of the same due to large competency contrast in clast and host.

2.3. Necked Boudins

Necked boudins are also called pinch-and-swell structures in the literature [11] [22] [33] [34]. Necked boudin “blocks” have moderate aspect ratios (L/W averaging 2.6) and are typically of classical boudin shape with bi-convex exteriors and less commonly parallel exteriors with a thinned inter boudin neck zone associated with host inflow [35].

Here in **Figure 3(c)** and **Figure 3(d)** both the varieties could be observed from the study area. The boudin train in **Figure 3(c)** demonstrates both the stages, as the inter-boudin neck is barely connected in the left segment of **Figure 3(c)**, while in the right side of the figure, typical biconvex exterior boudin, with moderate aspect ratio, can be observed. While **Figure 3(d)** shows rather parallel boudin exteriors and large aspect ratio in the left side boudin, the right side boudin exhibits transition from near parallel boudin exteriors to convex boudin exterior and the inter boudin neck barely connected. The inconclusive part rotation of slightly drawn/necked clast in 3(a) and chocolate boudin [44] in 3(b) accompanied by plastic deformation of host suggests large competence contrast between the host and the clast.

2.4. Tapering Boudin

Tapering boudin blocks have curved shapes with biconvex exteriors and are typically drawn into pointed terminations but can also be rounded, resulting in symmetric boudins with lens/lozenge, or less commonly, sausage shapes. Hence the alternative names “lenticular” boudins [33] [34] and stretched layer [25]. The one such example depicted in **Figure 4(a)**, where the boudin is having perfect shape with convex exteriors (Se) and pointed margins and isolated with no inter boudin neck. Tapering boudins with high aspect ratios also have high layer extension and boudin isolation (**Figure 4(b)**), suggesting that at high strain, the boudin block is being flattened concomitant with boudin separation [36]. **Figure 4(c)** exhibits tapering boudin within the competent bed, while the lower layers

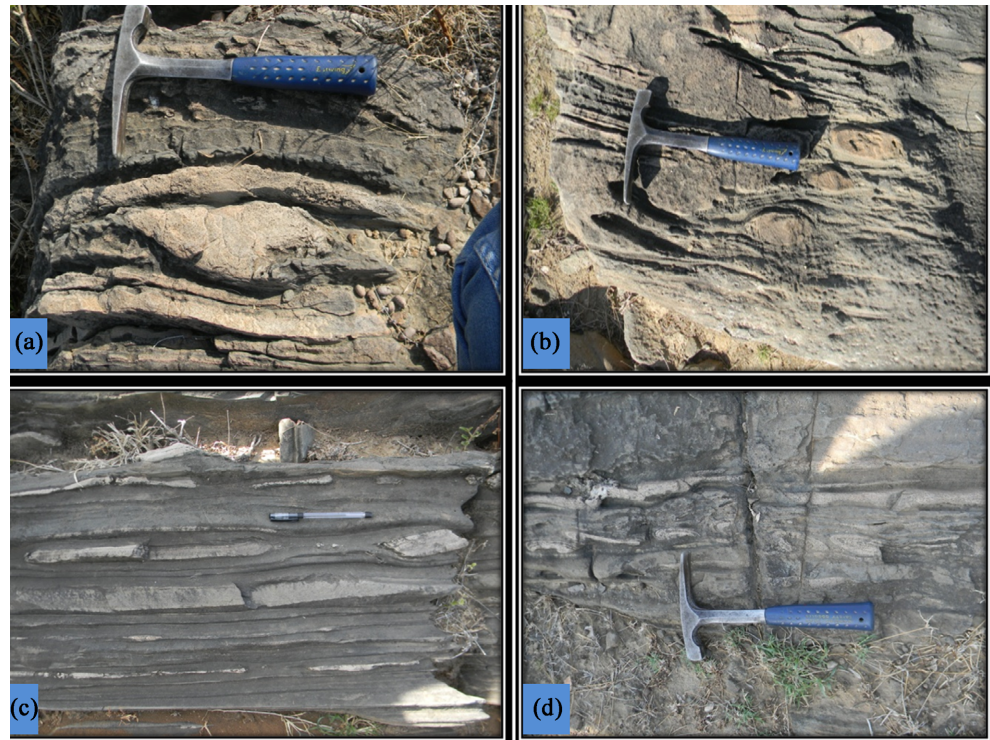


Figure 4. Various types of Boudins from the Quartzite-dolomite inter-layered sequence, Dariba area, Neem ka Thana belt [5]. (a) Tapering boudins exhibiting both outer surfaces biconvex exterior and the ends are in continuity with host, moderate aspect ratio (L/W), the modification of eastern end suggests second episode of shearing post boudinaging. (b) The multilayer drawn boudins; ends drawn as tails flowing with the host rock as plastic deformation, suggesting low competence contrast between the boudin and host. (c) Multilayer drawn boudins and pinch and swell structures indicating transitions between different stages [47]. (d) Shear zone defined by attenuated fold hinges, where the enveloping surface displays translational boudins.

show pinch and swell structure, may be due to thickness variation [45] [46]. The thicker beds are fractured in to tapering boudins, while within the same shear domain a thinner layer is pinched and swelled accompanied with the ductile shearing of the host [47]. **Figure 4(d)** demonstrates two different features: one is attenuated limbs of the folds due to progressive flattening type of shearing while the enveloping surface of the shear zone has developed dilatational fractures.

2.5. The Fish Mouth Boudins

The fish mouth boudins are in a way special category of tapering boudin where the margins get modified due to stress more active on margins and the clast and host have less competence contrast. The margins of the clast/boudin have a moderate aspect ratio (L/W) and convex exterior (S_e) become concave due to concentration of stress on margins and modifying the margins. This is due to the maximum stress being concentrated on the boudin edges; resulting in internal deformation of the boudin block and plastic deformation of the margins [33]. **Figure 5(b)** & **Figure 5(d)** depict the fish mouth boudins. The degree of concave curvature of boudin face, varies continuously from straight-face to fish mouth boudins



Figure 5. Various types of Boudins from the Quartzite-dolomite interlayer sequence, Dariba area, Neem ka Thana belt [42]. (a) Quartz vein exhibits necked boudins/pinch and swell structures in the maximum extension direction, while fractures develop in semipelite orthogonal to extension direction. (b) Multilayer carbonate-quartzite sequence in Dariba involved in formation of drawn boudins, note the modification of the margins and folding of boudin; evidences of post boudinage shearing, the left part of the figure, a fish mouth boudin, with one margin of each being concave, suggests modification of boudin. (c) Quartzite layer within carbonate at Dariba, depicts development of shear band like boudins, note the enveloping surface becoming sigmoidal and synthetic movement along the Sib (inter boudin surface). (d) Fish mouth boudin in sandy layer in impure dolomite from the belt; modification of margins indicates less competency contrast between the boudinaged material and host and a possible post boudinaging shearing.

[26] [28] which are also called “fish-head” [35] or “extreme barrel-shaped” boudins [33] [34], Fish mouth boudins are best developed in laminated rock types such as carbonates and by foliation boudinage [35].

2.6. Shearband Boudins

Shearband boudins are asymmetric with rounded rhomb to tapering lens shapes, typically with relatively high aspect ratios. The obtuse edge of the boudin is often rounded and the acute edge is drawn into a tapering wing by drag on inter boudin surface (Sib) (Figure 5(c)). Dilation across Sib and associated vein infill almost never occurs. Sib is typically a thin ductile shear zone with associated ductile grain refinement and grain-shape fabric [33]. All shear band boudins form by S-slip boudinage and are backward-vergent. Drag on Sib is almost always evident and synthetic to slip, a diagnostic feature that is responsible for the tapering sigma shapes of the boudin blocks. Shear band boudins of the sigmoid geometry are called “asymmetric pinch-and-swell structures” [20] [21] [27] drawing atten-

tion to the continuum between symmetric drawn boudins and asymmetric shear band boudins. In addition shearband boudins have been variously named “type II asymmetric boudins” [24] “sigmoidal boudinage” [11] “shear-fracture boudinage” [28] “backward-rotatedshear-bandboudins” [29] “surf asymmetric pull-apart structures” [20] “asymmetric extensional structures” [25] and “asymmetric pull-apart structures”: type 2A without discrete Sib and type 2B with discrete Sib [21]. We have adopted the name *shear band boudins* because their geometry so closely resembles that of shear-band cleavages [19] [44] [45] [46] [48] and in a single word best invokes an image of their form.

3. Boudin Modification

It is generally observed in the older mountain terrains like Aravalli and Delhi that the boudins once formed are modified, because these terrains have suffered multiple episodes of deformation accompanied with intense shearing. The verification of the above fact could be made in the present study area also and the same has been described here with the help of structures indentified and explained here. Boudin modification can take place either in a progressive deformation, where the high stress continues in a flattening type of deformation under same set of stress environment or requires a separate deformational activity subsequent to the boudin causing deformation [33]. It is very easy to identify modified boudins in some cases, while it becomes very difficult to unfold the deformational history of the events involved in the formation of a complex structure and relate it to the same. The boudin structures in **Figure 6(a)** to **Figure 6(c)** exhibit evidences of modifications of the boudin, while in **Figure 6(a)** the torn boudin train appears to be folded, the **Figure 6(b)** indicates folded boudins, still **Figure 6(c)** seems to show shortening of the boudins causing the folding of enveloping surface. As suggested [35] that the modification of boudins can be of two forms; Reworked boudin structures experienced shortening subsequent to formation [49]; those shortened in coaxial flow are called shortened boudins, in non-coaxial flow are called sheared boudins and where the boudin train as a whole has been folded, either in coaxial or non-coaxial flow, are called folded boudins. Reworked boudin structures form where boudins have been subjected to a second phase of deformation separated from the first by a significant period of time, *i.e.* polyphase, non-congruent structures. Sequential boudin structures experienced continued extension; this can imply that deformation during subsequent episodes was similar to the original condition that caused the boudinage, *i.e.* progressive congruent structures [35]. In all cases, crucial information is stored in both the inter boudin zone and any enveloping foliations present along the boudin exterior. In reworked boudin structures, this includes shortening or folding of inter-boudin vein infill, or solution or crenulation cleavage development in the inter-boudin zone or over the boudin exterior. This can be precisely witnessed in **Figure 2(a)** & **Figure 6(a)** where the inter boudin surface has been filled with plastically deformed ferruginous material and which

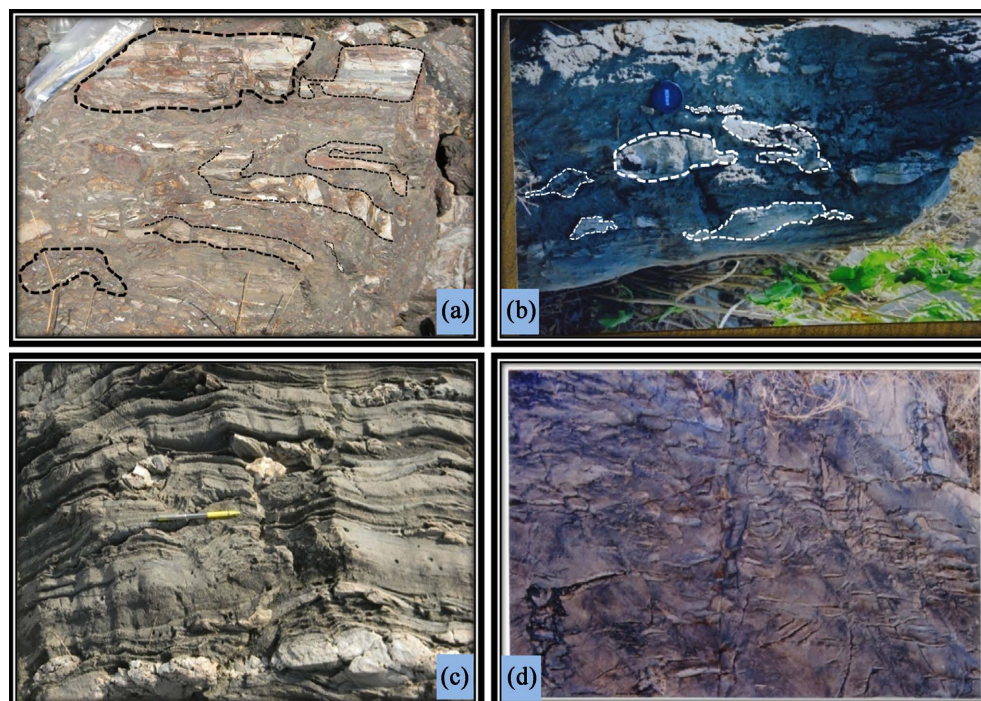


Figure 6. Modified boudins from Gursali ki Dhani area, Sikar district [42]. (a) Quartzite band involved in multilayer torn boudin formation, note the Sib being healed by plastically deformed ferrous material. The modification and folding of the earlier formed boudins, during subsequent deformation, off Gursali ki Dhani area. (b) Folded boudins in dolomite in Dariba area. Depicting more than one deformation/shearing episodes. (c) Tapering boudins in multilayer dolomite sequence, modified during the subsequent deformation causing shortening resulting in folding of the boudins as well as enveloping surface. Dariba area. (d) Open tension gashes and folded microolithons in siliceous dolomite Dariba area.

shows folding on close observation. Similarly there are quartz veins [49] within the inter boudin space which are folded (see **Figure 2(a)** where a small quartz vein emplaced within Sib has been folded to produce a sigmoid boudin), implying ployphase deformation. **Figure 6(b)** depicts folded boudins, which probably were the torn boudins in the earlier stage and have been folded during the progressive deformation under continued shearing for a longer period, the folded boudins suggests a moderate contrast between the host and boudin in competency. **Figure 6(c)** clearly demonstrates the shortening of the boudin during the subsequent deformation. Further, this shortening has caused transverse fractures in the enclosing rock layer orthogonal to the stretching direction/direction of shortening.

4. Discussion and Possible Inferences Drawn

The boudins of multiple generations of sequential and reworked type structures, all record the strain history of a rock mass. Unlike deformation fabrics, boudins are difficult to completely rework and obliterate; thus multiple boudin generations can preserve palaeo stretching axis directions from different deformational episodes. The suite of boudin types developed during different deformational

episodes, and indeed between different study areas, is often distinct. Hence, boudins may prove useful as indicators of flow regime during different deformational episodes and in characterizing different terranes [50] [51]. Though it may not be very easy to unfold the deformational history based on boudin structures especially if they are not oriented, symmetrical boudins like in the present case. Because of that nature, they hardly help establishing the relation with the bulk shearing sense, but still they contribute in inferring, generations of deformation, that any area has suffered, from which they are studied. The modification of the boudin, here especially depicted in **Figure 2(a)** and **Figure 6(a)**, suggests folding and not reworking meaning there by that the deformation was progressive in the particular episode, *i.e.* first deformation DF_1 (First fold of Delhi Orogeny), which has resulted in production of the torn boudins under the brittle deformation, and the continued deformation allowed folding of the boudin under ductile regime. The same has been depicted in the production of necked and pinch and swell structures. Hence, this can convincingly be inferred that the one generation of deformation was progressive in nature producing the sequential boudins *i.e.* (DF_1). The shortening of boudins accompanied by dilatational cracks orthogonal to extension direction, within the enveloping surface, suggests the reworking of the boudins produced during the earlier deformation, by subsequent deformational episode DF_2 (depicted in **Figure 6(c)**). The folding and shortening of the boudins including folding of the enveloping surface, presence of the fish mouth boudins, together indicate more strain on the margins and less competency contrast between the boudins and the host rock. All these features indicate a second episode of deformation post boudinaging. It is there for clear that the first deformation was progressive flattening type in nature which gave rise to various structures like torn boudin, necked boudin, pinch and swell structures and chocolate boudins including modification of boudins in terms of folding, while the reworked boudins including folded boudins, fish mouth boudins and folded boudins train are produced during the second deformation. Therefore, it could be clearly elucidated that the signatures of two different type of deformation could be identified and used to arrive at a conclusion. The boudin structures which are generally not studied for their larger role as an indicator of the deformational history have been attempted here, possibly been used effectively, in establishing the type of deformation in the area. However, more data especially the measurement of such features and associated structures and mathematical calculations to determine the actual shortening will be more helpful in precise interpretation of deformation history. However, the field based study without any extra cost of generation of lab data is worth a try.

Acknowledgements

The author is highly thankful to Ms Sushma Gupta, Ms Supriya Dewangan, Geologists, and Mr. S.J. Brahma and Sanjoy Debnath Sr. Geologists all from Geological Survey of India western Region Jaipur, for their contribution in preparing

a large scale map of the studied area. The author also expresses his deep sense of gratitude to Dr. P. Gupta (Retired Director GSI) for reviewing the text before it was submitted for publication. The undersigned also thank Dr. M.K. Pandit (Professor Retired. Uni. of Raj. Jaipur) for his constructive criticism of the text. The author also wishes to thank the anonymous scrutinizer of OJG for positive scrutiny which could make it publication worthy.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] Ray, J.N. (1983) Superposed Deformation in Delhi Rocks near Patan, Sikar distt., Rajasthan. *Journal of the Geological Society of India*, **24**, 229-236.
- [2] Behera, K.K., Mukhopadhaya, S., Kumar, P., Sarkar, S. and Srivastava, P.C. (2007) STM of Delhi Super Group of Rocks in Nim Ka Thana-Raipur-Patan Area, Sikar District, Rajasthan with Special Emphasis on Locating New Zones of Base Metal Mineralization. Unpub. GSI. WR. Rep. F.S. 2004-06.
- [3] Mondal, B. (2015) Second Level Exploration for Base Metal in West of Nanagwas Area, Sikar District, Rajasthan. Unpub. GSIWR. Rep. F. S. 2014-15.
- [4] Mondal, B., Debnath, S. and Dewangan, S. (2016) Report on Exploration for Base Metal in West of Nanagwas Area, Sikar District, Rajasthan. Unpub. GSI. WR. Rep. F.S. 2015-16.
- [5] Sharma, R.K. and Sharma, V. (2010) Investigation for Base Metals in Dariba Block, Sikar District, Rajasthan. Unpub. GSI. WR, Rep. F. S. 2007-08.
- [6] Brahma, S.J. and Gupta, S. (2015) Investigation for Base Metal in South-East of Kharagbinjpur, Sikar, District, Rajasthan. Unpub. GSI. WR Rep. F. S. 2014-15.
- [7] Lohest, M. (1909) L'origine des veines et des géodes des terrains primaires de Belgique. *Annales de la Société géologique Belgique B*, **36**, 275-282.
- [8] Papeschi, S. (2019) Features from Field. Blogs.
- [9] Ramsay, A.C. (1881) The Geology of North Wales. Memoirs of the Geological Survey of Great Britain, Volume 3.
- [10] Wilson, G. (1961) The Tectonic Significance of Small-Scale Structures and Their Importance to the Geologist in the Field. *Annals of the Society of Geologists de Belgique*, **84**, 424-548.
- [11] Ramsay, J.G. (1967) Folding and Fracturing of Rocks. McGraw-Hill, New York, 103-109.
- [12] Etchecopar, A. (1974) Simulation par ordinateur de la deformation progressive d'un aggregate polycristallin. Etude du développement de structures orientées parécroulement et cisaillement. Unpublished Ph.D. Thesis, University of Nantes, Nantes.
- [13] Etchecopar, A. (1977) A Plane Kinematic Model of Progressive Deformation in a Polycrystalline Aggregate. *Tectonophysics*, **39**, 121-139.
[https://doi.org/10.1016/0040-1951\(77\)90092-0](https://doi.org/10.1016/0040-1951(77)90092-0)
- [14] Hobbs, B.E., Means, W.D. and Williams, P.F. (1976) An Outline of Structural Geology. John Wiley and Sons, Hoboken, 278-280.
- [15] Lloyd, G.E. and Ferguson, C.C. (1981) Boudinage Structure: Some New Interpreta-

- tions Based on Elastic-Plastic Finite Element Simulations. *Journal of Structural Geology*, **3**, 117-128. [https://doi.org/10.1016/0191-8141\(81\)90009-2](https://doi.org/10.1016/0191-8141(81)90009-2)
- [16] Lloyd, G.E., Ferguson, C.C. and Reading, K. (1982) A Stress-Transfer Model for the Development of Extension Fracture Boudinage. *Journal of Structural Geology*, **4**, 355-372. [https://doi.org/10.1016/0191-8141\(82\)90019-0](https://doi.org/10.1016/0191-8141(82)90019-0)
- [17] Blumenfeld, P. (1983) Le "tuilage des megacristaux", un critere d'écoulement rotationnel pour les fluidalites des roches magmatiques; Application au granite de Barbey. *Bulletin de la Société géologique de France*, **25**, 309-318. <https://doi.org/10.2113/gssgfbull.S7-XXV.3.309>
- [18] Simpson, C. and Schmid, S.M. (1983) An Evaluation of Criteria to Deduce Sense of Movement in Sheared Rocks. *Bulletin of the Geological Society of America*, **94**, 1281-1288. [https://doi.org/10.1130/0016-7606\(1983\)94<1281:AEOCTD>2.0.CO;2](https://doi.org/10.1130/0016-7606(1983)94<1281:AEOCTD>2.0.CO;2)
- [19] Simpson, C. (1984) Borrego Springs-Santa Rosa Mylonite Zone: A Late Cretaceous West-Directed Thrust in Southern California. *Geology*, **12**, 8-11. [https://doi.org/10.1130/0091-7613\(1984\)12<8:BSRMZA>2.0.CO;2](https://doi.org/10.1130/0091-7613(1984)12<8:BSRMZA>2.0.CO;2)
- [20] Hanmer, S.K. (1984) The Potential Use of Planar and Elliptical Structures as Indicators of Strain Regime and Kinematics of Tectonic Flow. Current Research, Part B, Geological Survey of Canada, Paper 84-1B, 133-142. <https://doi.org/10.4095/119569>
- [21] Hanmer, S. (1986) Asymmetrical Pull-Aparts and Foliation Fish as Kinematic Indicators. *Journal of Structural Geology*, **8**, 111-122. [https://doi.org/10.1016/0191-8141\(86\)90102-1](https://doi.org/10.1016/0191-8141(86)90102-1)
- [22] Van der Molen, I. (1985) Interlayer Material Transport during Layer-Normal Shortening. Part II. Boudinage, Pinch-and-Swell and Migmatite at Sondre Stromfjord Airport, West Greenland. *Tectonophysics*, **115**, 297-313. [https://doi.org/10.1016/0040-1951\(85\)90143-X](https://doi.org/10.1016/0040-1951(85)90143-X)
- [23] Ramsay, J.G. and Huber, M.I. (1987) The Techniques of Modern Structural Geology. Volume 2: Folds and Fractures. Academic Press, London, 516-633.
- [24] Goldstein, A.G. (1988) Factors Affecting the Kinematic Interpretation of Asymmetric Boudinage in Shear Zones. *Journal of Structural Geology*, **10**, 707-715. [https://doi.org/10.1016/0191-8141\(88\)90078-8](https://doi.org/10.1016/0191-8141(88)90078-8)
- [25] Lacassin, R. (1988) Large-Scale Foliation Boudinage in Gneisses. *Journal of Structural Geology*, **10**, 643-647. [https://doi.org/10.1016/0191-8141\(88\)90030-2](https://doi.org/10.1016/0191-8141(88)90030-2)
- [26] DePaor, D.G., Simpson, C., Bailey, C.M., McCaffrey, K.J.W., Bean, E., Gower, R.J.W. and Aziz, G. (1991) The Role of Solution in the Formation of Boudinage and Transverse Veins in Carbonate Rocks at Rheems, Pennsylvania. *Geological Society of America Bulletin*, **103**, 1552-1563. [https://doi.org/10.1130/0016-7606\(1991\)103<1552:TROSIT>2.3.CO;2](https://doi.org/10.1130/0016-7606(1991)103<1552:TROSIT>2.3.CO;2)
- [27] Hanmer, S. and Passchier, C. (1991) Shear-Sense Indicators: A Review. Geological Survey of Canada. Paper 90-17, 72 p. <https://doi.org/10.4095/132454>
- [28] Swanson, M.T. (1992) Late Acadian-Alleghenian Transpressional Deformation: Evidence from Asymmetric Boudinage in the Casco Bay Area, Coastal Maine. *Journal of Structural Geology*, **14**, 323-341. [https://doi.org/10.1016/0191-8141\(92\)90090-J](https://doi.org/10.1016/0191-8141(92)90090-J)
- [29] Swanson, M.T. (1999) Kinematic Indicators for Regional Dextral Shear along the Norumbega Fault System in the Casco Bay Area, Coastal Maine. Geological Society of America Special Paper 331, 1-23. <https://doi.org/10.1130/0-8137-2331-0.1>
- [30] Fossen, H. (2010) Chapter 14. Boudinage. In: *Structural Geology*, Cambridge University Press, Cambridge, 271-284. <https://doi.org/10.1017/CBO9780511777806.016>
- [31] Goscombe, B. and Passchier, C.W. (2003) Asymmetric Boudins as Shear Sense In-

- dicators—An Assessment from Field Data. *Journal of Structural Geology*, **25**, 575-589. [https://doi.org/10.1016/S0191-8141\(02\)00045-7](https://doi.org/10.1016/S0191-8141(02)00045-7)
- [32] Jones, A.G. (1959) Vernon Map-Area British Columbia. Memoir Geological Survey Branch, Canada 296, 1-186. <https://doi.org/10.4095/100518>
- [33] Penge, J. (1976) Experimental Deformation of Pinch-and-Swell Structures Unpublished M.Sc. Thesis, Imperial College, University of London, London.
- [34] Ben, D.G., Passchier, C.W. and Hand, M. (2004) Boudinage Classification: End-Member Boudin Types and Modified Boudin Structures. *Journal of Structural Geology*, **26**, 739-763. <https://doi.org/10.1016/j.jsg.2003.08.015>
- [35] Ghosh, S.K. and Sengupta, S. (1999) Boudinage and Composite Boudinage in Superimposed Deformations and Syntectonic Migmatization. *Journal of Structural Geology*, **21**, 97-110. [https://doi.org/10.1016/S0191-8141\(98\)00096-0](https://doi.org/10.1016/S0191-8141(98)00096-0)
- [36] Arslan, A., Passchier, C. and Cohen, D. (2008) Foliation Boudinage. Enlighten Publications. *Journal of Structural Geology*, **30**, 291-309. <https://doi.org/10.1016/j.jsg.2007.11.004>
- [37] Sengupta, S. (1983) Folding of Boudinaged Layers. *Journal of Structural Geology*, **5**, 197-210. [https://doi.org/10.1016/0191-8141\(83\)90044-5](https://doi.org/10.1016/0191-8141(83)90044-5)
- [38] Treagus, S. and Lan, L. (2000) Pure Shear Deformation of Square Objects, and Applications to Geological Strain Analysis. *Journal of Structural Geology*, **22**, 105-122. [https://doi.org/10.1016/S0191-8141\(99\)00143-1](https://doi.org/10.1016/S0191-8141(99)00143-1)
- [39] Treagus, S. and Lan, L. (2003) Simple Shear of Deformable Square Objects. *Journal of Structural Geology*, **25**, 1993-2003. [https://doi.org/10.1016/S0191-8141\(03\)00049-X](https://doi.org/10.1016/S0191-8141(03)00049-X)
- [40] Treagus, S.H. and Lan, L. (2004) Deformation of Square Objects and Boudins. *Journal of Structural Geology*, **26**, 1361-1376. <https://doi.org/10.1016/j.jsg.2003.12.002>
- [41] Mukherjee, S. (2017) Review on Symmetric Structures in Ductile Shear Zones. *International Journal of Earth Sciences (Geologische Rundschau)*, **106**, 1453-1468. <https://doi.org/10.1007/s00531-016-1366-4>
- [42] Sharma, R.K., Brahma, S.J., Debnath, S., Dewangan, S. and Gupta, S. (2017) Large Scale Map of the Host Lithology in Dokan-Dariba Toda Ramliyas Area.
- [43] Passchier, C.W. (1997) The Fabric Attractor. *Journal of Structural Geology*, **19**, 113-127. [https://doi.org/10.1016/S0191-8141\(96\)00077-6](https://doi.org/10.1016/S0191-8141(96)00077-6)
- [44] Ghosh, S.K. (1988) Theory of Chocolate Tablet Boudinage. *Journal of Structural Geology*, **10**, 541-553. [https://doi.org/10.1016/0191-8141\(88\)90022-3](https://doi.org/10.1016/0191-8141(88)90022-3)
- [45] Janos, U., *et al.* (2021) The Effect of Layer Thickness on Brittle Boudinage in 3D Earth Arxiv. Structural Geology, Tectonics and Geomechanics, RWTH Aachen University Lochanerstrasse 4-2052056 Achaean Germany.
- [46] Lister, G.S. and Snoke, A.W. (1984) S-C Mylonites. *Journal of Structural Geology*, **6**, 617-638. [https://doi.org/10.1016/0191-8141\(84\)90001-4](https://doi.org/10.1016/0191-8141(84)90001-4)
- [47] Bamberg, B., von Hakge, C., Virgo, S. and Urai, J.L. (2021) Spacing and Strain during Multiphase Boudinage in 3D. Advances in Modern Structural Geology: (A Special Issue in Honor of the Life and Work of John Ramsay of Journal of Structural Geology). *Structural Geology*, **161**.
- [48] Kenis and Situbin, M. (2007) About Boudins and Mullions in the Ardenne elfel Area Belgium Germany. *Geologia Belgica*, **10**, 79-91.
- [49] Pushwanto, E., AlAfif, M., Farisan, A., Hastria, D., Rahrjo, P.D., Arisa, D. and Tua-

- kia, M.Z. (2021) Deformation Mechanism of Boudin Structures at the Bulukuning Area, Banjarnegara. *IOP Conference Series: Earth and Environmental Science*, **789**, Article ID: 012070. <https://doi.org/10.1088/1755-1315/789/1/012070>
- [50] Jacko, S., Farkasovsky, R., Kondela, J., Mikus, T., Scrbakova, B. and Dirnerova, D. (2019) Boudinage Arrangement Tracking of Hydrothermal Veins in the Shearzone Example from the Argentiferous Strieborna Vein Western Carpathian. *Journal of Geoscience*, **64**, 179-195. <https://doi.org/10.3190/jgeosci.291>
- [51] Passchier, C.W. and Druguet, E. (2002) Numerical Modelling of Asymmetric Boudinage. *Journal of Structural Geology*, **24**, 1789-1804. [https://doi.org/10.1016/S0191-8141\(01\)00163-8](https://doi.org/10.1016/S0191-8141(01)00163-8)