Origin of Ball and Pillow-like Structures in Tanjero and Kolosh Formations in Sulaimaniya area, NE-Iraq

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Abstract
Tanjero and Kolosh Formations as clastic dominated units consist mainly of alternation of medium bedded sandstone and calcareous shale. The formations crop out as a northwest-southeast belt in northeastern Iraq near the border with Iran in the High Folded and Imbricated Zones. The outcrops of the formations, in Sulaimaniya area, contain many ball and pillow-like structures These structures are studied in the field in several localities and concluded that they are formed during burial after deposition by differential load pressure and tectonic stresses. Different stages of the development are found in the field and all combined to show their paragenesis. The author used, on the basis of field data, suitable sketch and field photos for establishing a conceptual (deterministic) model of development. The model includes jointing and possibly fracturing (as starting point during burial stage) and converting to spheroidal or pillow-like bodies at the final stages of developments by tectonic deformation and load pressure. No evidence is found to relate the recorded ball-and- pillow to the deposition or early diagenetic process.

Keywords: ball and pillow, sedimentary structure, deformation, Tanjero Formation, Kolosh Formation, geology of Kurdistan, deformation.

Introduction
Pettijohn (1975)[1], Potter and Pettijohn (1977)[2] found Ball and pillow structures in both sandstone and limestone. The former author ascribed these structures to foundering of unconsolidated sand into quasiliquid substrate. He added that they are post depostional structures before deposition of overlaying strata "penecontemporaneous deformation". The latter authors argued in detail all aspects of these structures they attributed them to different origins such as foundering of sand beds and slump.

Ball and pillow structures are defined by Bate and Jackson (1980)[3] as: primary sedimentary structure found in sandstones and some limestones, characterized by hemispherical or kidney-shaped mass resembling ball and pillows and commonly attributed to foundering: e.g. a flow roll or pseudonodules Tanjero and Kolosh Formation belong to Maastrichtian and Paleoceneages respectively. They are identified as clastic dominated units, consisting mainly of alternation of medium-bedded sandstone and calcareous shale. The formations crop out as a northwest-southeast belt in northeastern Iraq near the border with Iran in the High Folded and Imbricated Zones (Buday 1980 [4] and Buday and Jassim, 1987[5]). According to Karim (2004)[6], both formations were deposited in an early foreland basin in front of an advancing positive land of the Iranian plate.

The outcrops of both formations, in Sulaimaniya area, contain many ball and pillow structures which consist of

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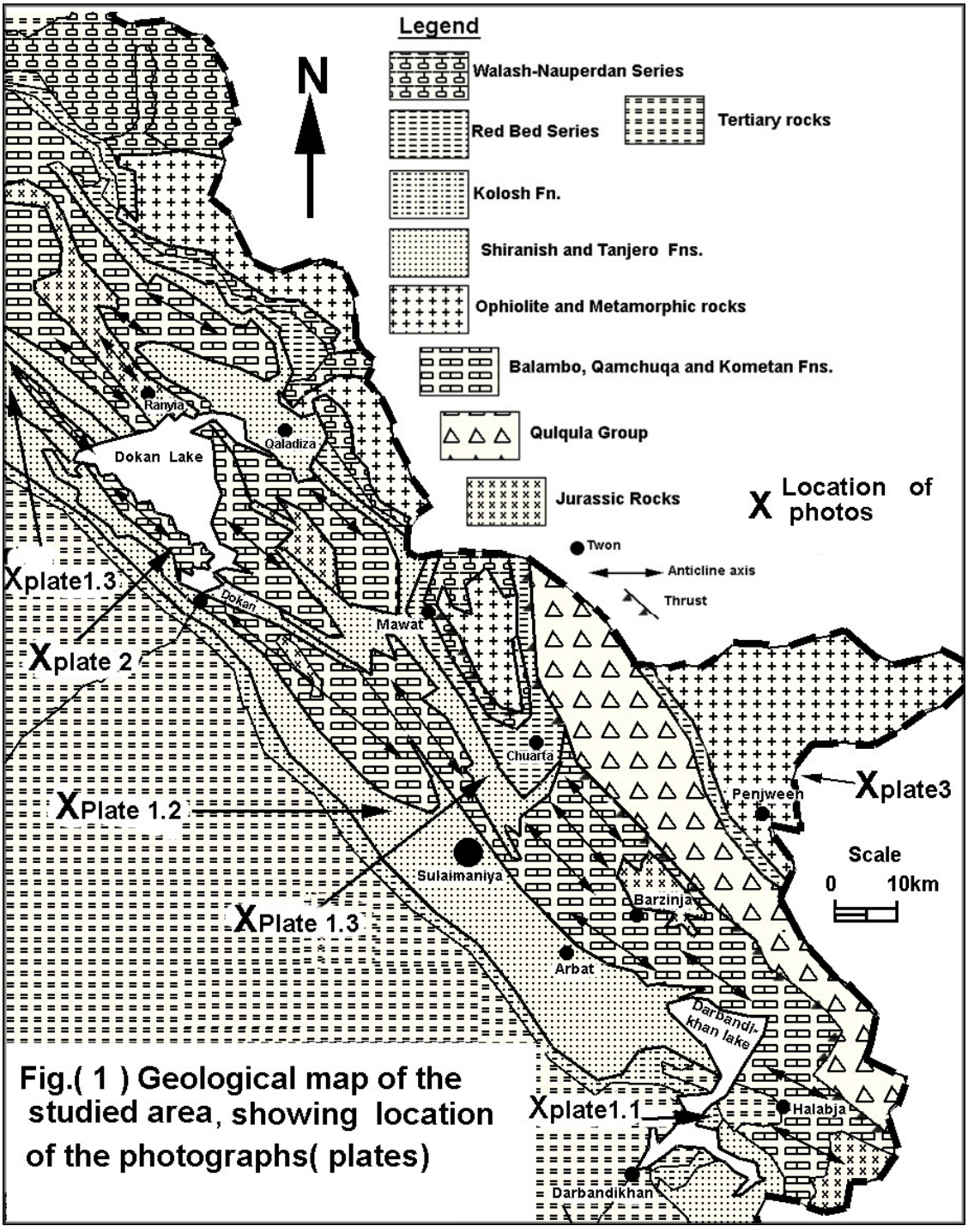


Fig.(1) Geological map of the studied area, showing location of the photographs(plates)

ellipsoidal, or pillow like sandstone and limestone bodies. These structures are observed, by the author, in different types of rocks supposed to be deposited in different environments such deep and shallow. These bodies range in size both formations, from 4cm to more than 20 cm in diameters (Plate1).

The bodies of the structures are composed of fine or medium sized clayey or clean sandstones and in some case they are composed of limestones (Plate 2.6). The

pillows or balls may be connected by necks or completely isolated and floating freely in marly or shally matrix (Plate 1.4, 2.4, 2.5 and Fig. 2.4D).

Those which are exist in the thick beds of marl or shale is well developed and closed to sphere (Plate1.3, 1.4 and 2.5) while those found in the sandstone-dominated intervals are badly developed (Fig.2). Most structures show concentric lamination while others are structureless.

Origin of the structures

Al-Shammary and Yahya (1997) studied similar structures in the Kolosh Formation and concluded that they were developed bymovement of unconsolidated sand sediments due to specific gravity. Al-Rawi (1981, p.45) [8] showed similar structures photographically and attributed them to slump structures. Recently Lawa(2004, p.226) [9] found also ball and pillow structures in Kolosh Formation and included them in the sedimentary structures which regarded them as evidence for criteria of synsedimentary tectonic activity in the basin of the formation.

Ball-and-pillow structures in the present study are interpreted to be late diagenetic structures (deformational and post depostional sedimentary structures) developed after lithification during burial and subsequent uplifting.

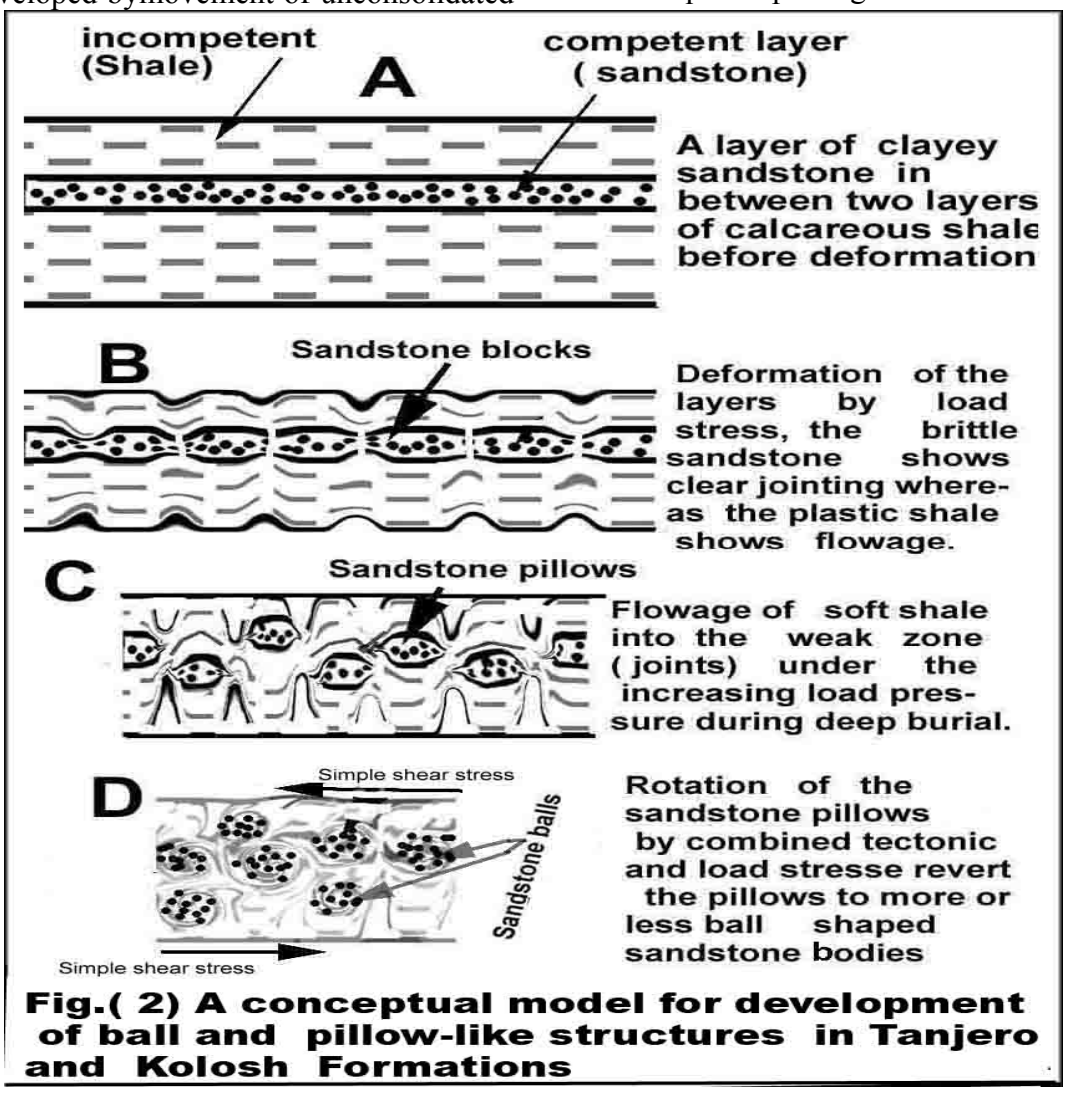


Fig.(2) A conceptual model for development of ball and pillow-like structures in Tanjero and Kolosh Formations

Stages of paragenesis of the Structures

Through fieldworks the two end members (jointed blocks) and intermediate stages of ball-and-pillow structures are indicated. All the stages are photographed and are illustrated by suitable diagrams, which combined as a conceptual model (natural model) for development of these structures. The model includes and passes through the following steps:

1. The initial stage starts with jointing and fracturing of thin or medium bedded sandstone or limestone during burial by differential pressure. The beds are must be stiff (competent) and intercalated between thick beds of soft marl or shale (Fig.2A and Plates 1.1 and 2.1). These form angular (rectangular and rhombic joints and fractures) blocks of sandstone.

2. When the tectonic pressure increase the soft marl is injected into the spaces between the blocks through fractures. The same process may occur by differential load pressure but of less effect than tectonic. This flowage is due to plastic flow of soft enveloping soft layers. This leads to smoothing of edges of the blocks. This strongly analogous to the flow of plastic salt inside country rocks shown by Warren, (1999)[10]. The sketches showed by him include smoothing of that part of country rocks directly in contact with the moving salt materials. Hyndman, (1979) [11] discussed similar processes by forceful injection. It is possible that blocks are dislocated from their position in all direction. This stage of ball and pillow is similar to the development of boudin (sausage) which discussed by Davis and Rhynolds (1996) [12]. Potter and Pettijohn (1977, p.201)[2] found these structures in highly deformed shale which wrapped the pillows by squeezing.

In this stage an edgeless polygonal structure is formed which is transitional between the original joints and the ball-and-pillow structures (Plates 1.2, 2.2, 2.3 and Fig.2B). This stage includes further possible dislocation of the blocks so that each one is isolated from the adjacent ones. This stage is similar to development of boudinage structures in highly deformed competent beds.

3. Further increase of the pressure and flowage of marl causes removal of all edges with possible rotation of blocks. The rolling is attributed to flow of soft material in the different direction due to tectonic stresses. Rotation is not impossible in rocks as Carey (1998, 1001) [13] mentioned and illustrated by diagram rotation of resistant grain in metamorphic rocks during syn-tectonism. Finally the ball-and-pillow structure is developed (Plate 1.3, 1.4, 2.6 and fig.2C and D). Davis and Rhynolds (1996) [12] mentioned rotation of boudins during development and deformation.

Karim (2003b, p12) [14] showed the rotation of competent inclusions by flowage of soft material in the black marble of Penjween area. Van Den and Brun (1987)[15] studied rotation of competent bodies (inclusions) in an incompetent matrix by high strain shear zones. Rosas *et al.* (2001)[16] showed by experiment rotation of rigid inclusion by simple shear in a viscous matrix. The blocks and matrix, in this stage were deformed more or less plastically while they underwent brittle deformation in first stage. We must not ignore the role of weathering in modification of final shape of the structures and magnifying the miner difference in composition and hardness.

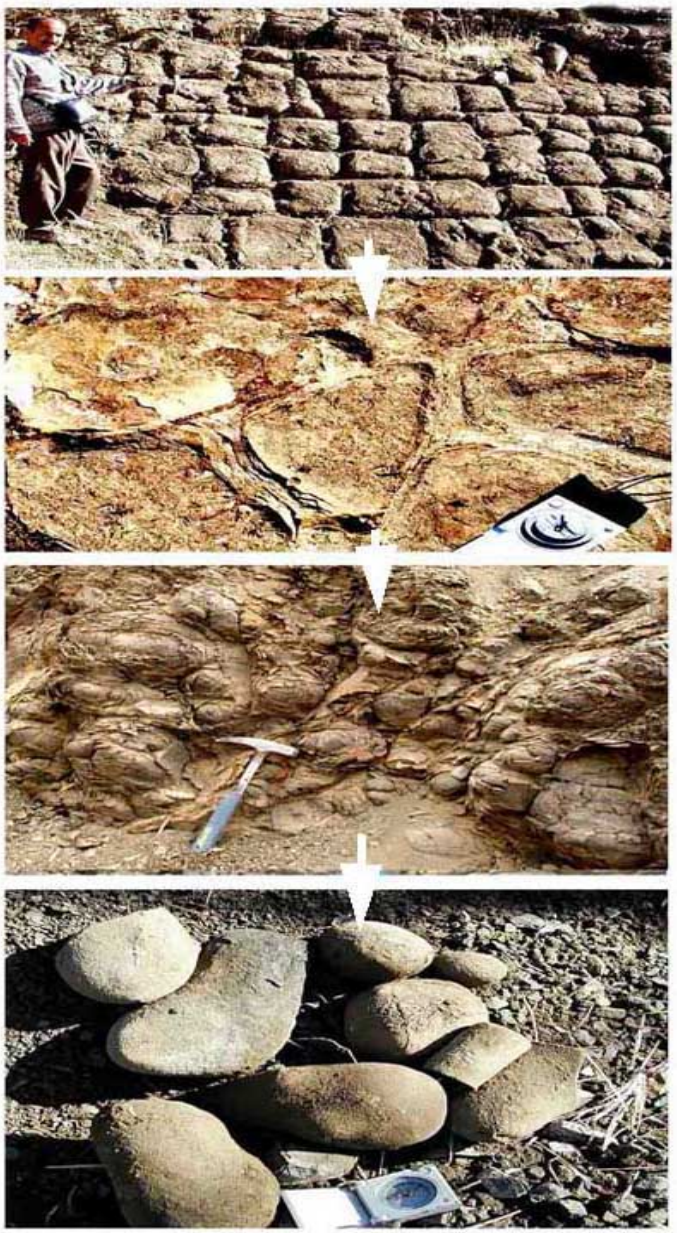
But the original shape is due to the effect of stress and diagenetic processes.

4-The ions-bearing solution migrates from the compressed soft materials into block precipitating cementing materials and converting them to coherent bodies. Mcbridge *et al*. (2003)[17] found large spheroidal calcite concretion (20-200cm) in sandstone of Wyoming and Utah, U.S.A. which grown displacively from solution bearing Ca ions. Pettijohn *et al*, (1987, p.122) [18] showed large balls of cross bedded sandstone. They classified them under the concretion and attributed their development to transport of solution and cementation.

The evidences for the late diagenetic origin of these ball and pillows-like structures are cited as following:

Plate 1

Stages of the development of the ball-and-pillow in the Tanjero Formation



(1)The initial form of ball and pillow (as supposed in this study) in previously jointed thin bedded sandstone. Some blocks are already changed into pillow like structures at upper right of the photo, 1km south of Nawar village,Tanjero type section.

(2) Polygonal ball and pillow structures at a stage of deveolpement which resembles mud cracks. Lower part of the formation, south of Sutka village, northeasat of Tasluja Town (camp)

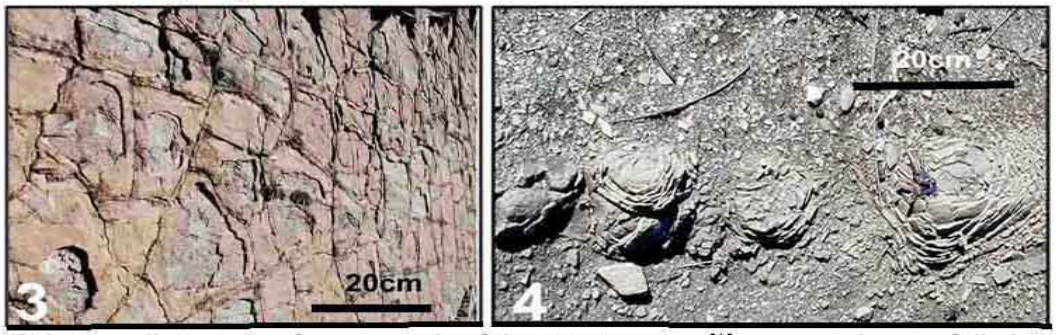
(3)Well developed pillow structures in the shale exposed along new road cut, 500m east of Zarda Bee Village, Chuarta area. The pillows consist of clayey sandstones. They shows spheriodal exfoliation due to weath-ering.

(4) Very well developed ball and pillow structures, collected in shale near the contact with Kolosh Formation, 2km east of Jally Village, Smaqully Valley. These structures are collected along a line which previously existed as a thin bed of sandstone later deformed into ball or pillow by high pressure and flowage of soft shale around the sandstone blocks.

Plate2

Stages of the development of the ball-and-pillow in the Kolosh Formation

(1) This photo is supposed to be the initial development of ball and pillow structures by which is a medium thick bedded sandstone divided into blocks by orthogonal joints
(2)Subsequent stage of development in which the blocks show more deformation and less angularity.



(3) Intermediate stage of paragenesis of the structures, with more or less exfoliation and circularity.
(4)Totally well developed ball-and- pillow strucutres which consist of sandstone floating in calcareous shale. They show clear exfoliation (spheroidal weathering) .

(5) Detail of spheroidal weathering as digitally enlarged right side of photo no. 4
(6) Both Tanjero and Kolosh Formations contain balls or pillows of limestone or marly limestone but not so much developed as sandstone ones. In some places these structures resemble conglomerate. All the photos are taken at the east and north of Kalkasmaq village, Dokan area.

A. They occur in the more or less deformed successions (faulted and folded).

B. They are seen inside soft massive beds of marl or shale without sedimentary bedding and lamination, which show clear disturbance flowage of materials in different direction. Originally the marl or shale possibly contained many laminations and few sandstone beds (Fig.2A). But later they changed to massive ones by deformation.

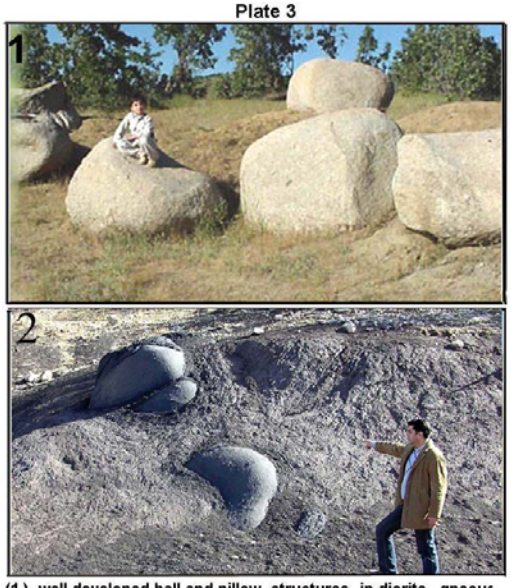
C. This study doesn't refuse existence of ball and pillow of sedimentation origins but during extensive fieldwork, ball-and-pillow structures, of this type were not found. They are observed in rocks supposed to be deposited in deep environment which were so calm that these structures can not be formed there. Therefore, nearly all these structures in

Tanjero and Kolosh Formations are of late diagenetic origin formed during and after burial and later tectonic deformation. Ramsay and Lisle (2000, p.993-1017) [19] well documented and analyzed ball-like structures (Boudins) in calc-silicate marbles. They attributed them to flowage of rock materials under simple shear stress.

Ball and pillow in other rocks rock

In the area of the study these structures are also fond in igneous rocks at the border between Iraq and Iran, near Kani Miran and Kani Shekhan villages. The balls are large and spherical or ellipsoidal in shape (Plate 3.1). In the field one can see detached and undetached balls from the diorite body. Their developed is same as illustrated schematically in the figure 2. Also they found in the shale of Jurassic rocks at 5km northeast of Barzinja town, near Chiara village. They are consisted of bitumineous sandstone floating in the matrix of shale (plate3.2)

Plate 3



(1) well developed ball and pillow structures in diorite gneous rocks. The igneous bodies covered by weathered material below the stuctures, Iran- Iraq border east of Penjween town. Near Kani Miran and Kani Hanjeer villageds (on the paved road between Penjween and Marwan towns).

(2) Pillows of bituminous sanstone in Jurassic rocks (shale) at 5km west of Barzinja town near Chinra Village.

The material between the balls are deformed and crushed. These materials are also showing flowage between the balls. These balls is located in more tectonically active (Thrust Zone) than the area of Kolosh and Tanjero Formations. Therefore the deformation forces were enough to develop ball and pillows structures in hard, competent and massive igneous body by the same ways as shown in the figure 2.

Conclusions

The paper has the following conclusions:

1. Many deformational structures are found during fieldwork, which are related to the end members of a proposed process of development of ball-and-pillow-like structures in Tanjero and Kolosh Formations.

2. The field evidences showed that these structures started with jointing of the competent sandstone beds (as one end member and completed with well developed ball and pillow structures (as other end member).

3. The two end members and transition structure are all combined together and showed by field photographs and discussed with sketches to illustrate field-based conceptual model (deterministic model) of paragenesis of these structures.

4-The ball-and-pillows are well developed in fine grain intervals while in coarse grain intervals not so.

5. These structures are studied in the field in several localities and concluded they are formed during deep burial after deposition by differential load pressure and subsequent tectonic horizontal stresses.

5- Same structure, in large scale, are found also in diorite and shale of Jurassic rocks in the studied area. Therefore the model of development of ball and pillow

structures is valid for igneous and metamorphic rocks also.

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بنەمای (اصل) پێکهاتەی شێوە خڕو و بالیفی لە دوو پێك هاتووی تانجرۆ وە کۆلۆش دا لە ناو چەوی سلێمانی، باکووری رۆژهەلاتی عێراق

کمال حاجی کریم
بەشی جیو لوجی/زانکۆی سلیمانی / هەرێمی کوردستان-عێراق

پووختە

پێکهاتوی تانجەرۆ وە کۆلۆش وەکو یەکەیەکی دەرکەوتون لەناوچەی تکتونی سەریەك کەوتووە وە ناوچەی چەماوە لە سەرووی رۆژهەلاتی عێراق0 ئەم دوو پێکهاتووە درێژ دەبێتەوە لە نزیك سنوری ئێران وەکو پشتێنەیەکی تەسك بەرەو سەردوی رۆژ ئاوا - خواروی رۆژهەلات0 پێکهاتون لە چینی یەك لەدوای یەکی بەردی لم و سیلت و مارل {یان شەیلی کلیسی } مێرەیت و بەردی کلسی گیانداری ئەم دوو پێکهاتووە گەلیك دروستبووی خر یان بالیفی تێدایە لێکۆلینەوەیان لێکراوە لە کەلێك ناوچەی جیاواز وە دەرکەوت کە دروست بوون بەهۆی دفنی قووڵەوە پاش نیشتن لەژێر کاریگەری کێشی بەردی سەرەوە وە هێزی تکتۆنی. گەلیك پلەی جیاواز دۆزراوەتەوە وە بە یەکەوە بەستراون بۆ رشوونکردنەوەی رەکەزی کەشەکردن وە هەروەها مودیلێکی حقیقی دروست کرا . ئەم مۆدێلە دەست پێدەکات کە بە دروست بوونی (Joint) وەکۆ سەرەتای لە کاتی دفندا وە لە کۆتایدا دەبێت بە بە دروست بووی خڕ وە بالیفی بەهۆی کاریگەری تێکچوونی تکتۆنیەوە وە پەستانی کێشی چینەکانی سەرەوە. پەیوەندی نەدۆزرایەوە لە نیوان نێوان ئەم دروست بووانەداو نیشتنی سەرەتای یان گۆڕانکاری تحویری سەرەتای.

أصل التراكيب الكروية والوسادية في تكويني تانجيرو و كولوش ، منطقة السليمانية، شمال شرق العراق

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إن تكويني تانجيرو و كولوش عبارتا عن وحدتان صخريتانيتكونان بصورة رئيسية من تبادل بين صخور الفتاتية الرملية ولغرينية و المارل. تمتد مكاشفهما كنطاق ضيق باتجاه شمال الغرب –جنوب الشرق قرب الحدود الايرانية في نطاقي التراكب والطيات العالية. يحتوي التكوينيين على تراكيب رسوبية كروية و وسادية حيث درست في عدة أماكن في الحقل و استنتجت على إن هذه التراكيب شكلت خلال دفن العميق بعد الترسيب بواسطة ثقل الصخور الفوقية و الا جهادات التكتونية. وجدت المراحل المختلفة في الحقل وتم اندماج هذه المراحل لكي يبين اصل تطورهم و شكلت كنموذج الحقيقي التطبيقي. يبدا هذا النموذج في البداية بالعملية ا تكوين الفواصل (كمرحلة البداية أثناء الدفن ثم يظهر في النموذج تحور الكتل المفصولة إلي التراكيب الكروية أو الوسادية في المراحل التطور النهائية كنتيجة التشوهات التكتونية و ضغط الطبقات الفوقية. الباحث لم يجد العلاقة بين هذه التراكيب و العملية الترسبية. و العملية التحويرية الاولية

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