PERGAMON

Journal of Structural Geology 21 (1999) 691–693

JOURNAL OF STRUCTURAL GEOLOGY

Kinematics of large scale tip line folds from the High Atlas thrust belt, Morocco: Reply

Bertrand Saint Bezar, Dominique Frizon de Lamotte*, Jean Luc Morel, Eric Mercier

Université de Cergy-Pontoise, Département des Sciences de la Terre (CNRS ESA 7072), F95 031 Cergy-Pontoise Cedex, France

Received 23 December 1998; accepted 22 February 1999

The discussion by Storti and Salvini concerns the interpretation of a recumbent syncline developed at the front of the Jebel Ta'bbast anticline. We have described this relatively small-scale structure as a 'puzzling structure'. This meant, in our mind, an unusual feature for a zone situated very close to a mountain front. The origin of this recumbent syncline was treated very briefly (about ten lines in our paper). So, we welcome the opportunity to present further our data and interpretation.

Storti and Salvini emphasise the existence of recumbent folds in many fold–thrust belts. However, their examples pertain to structural contexts quite different to the one studied in our paper. The area studied by Rowan (1993) is situated in the inner part of the external Alps (Helvetic nappes) where recumbent folding is the rule because of a very high shortening ratio. Additionally the major structures are detachment folds but not ramp-related folds. In the Rockies, the examples discussed by Boyer (1986) present recumbent anticlines due to the hinge collapse (Ramsay, 1974) at the top of anticlines exhibiting kink-like geometry. Such a process cannot lead to recumbent synclines.

Coming back to the High Atlas, what are the main differences between our model and the one defended by Storti and Salvini? We have proposed that the recumbent syncline located at the Jebel Ta'bbast front results from a collapse initiated along the forelimb subsequently accentuated by a 'caterpillar' delamination during southward transport on a shallow upper flat. In our opinion the recumbent syncline appeared at a relatively late stage of the anticline growth. The progressive rollover fault propagation fold model (Storti and Salvini, 1996) assumes that the recumbent syncline and an adjacent recumbent anticline (never observed in the field) are developed during the building of the Jebel Ta'bbast as a fault propagation fold. The model consequently supposes that the leading syncline has been developed simultaneously since the first increment of the Jebel Ta'bbast building.

From a purely geometrical point of view, the Storti and Salvini model appears as an interesting possibility. However, it does not take into account the following key points coming mainly from the regional geology:

- The Jebel Ta'bbast is a shallow structure in a domain where tectonic and erosional processes interact continuously. It is likely that erosion was active since the beginning of the anticline building. So that the continuity of the uppermost layers has been disrupted very early favouring the development of collapse features along both limbs of the anticline but mainly along its steep forelimb. Collapse structures have been described for decades by Harrison and Falcon (1934) in the Zagros Mountains of Iran. The most striking feature they discussed is the 'flap-structure' where a limestone sheet "has bent over (...) without breaking" (Harrison and Falcon, 1934, p. 534) until a completely overturned position has been attained (Fig. 1). Geometrically, the recumbent syncline that we have described is a 'flap-structure'. De Sitter (1956) discussing the purely gravitational origin of the Harrison and Falcon flap suggested that it "had originated in the folding stage (as disharmonic features) and was accentuated later by gravitational collapse" (De Sitter, 1956, p. 275). Taking into account the recent developments in the understanding of folding, we propose to reverse

* Corresponding author.
E-mail address: frizon@u-cergy.fr (D. Frizon de Lamotte)

0191-8141/99/$ - see front matter © 1999 Elsevier Science Ltd. All rights reserved.
PII: S0191-8141(99)00088-7

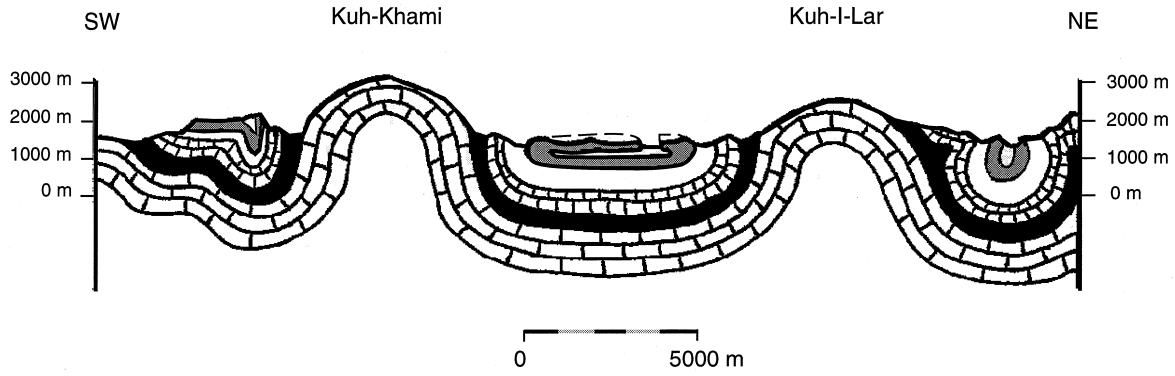

Fig. 1. 'Flap-structures' in the Tasir Syncline (redrawn from Harrison and Falcon, 1934). Beds involved in the convergent recumbent synclines are Asmari limestone of Eocene–Oligocene age. Limestone outcropping in the anticlines is of Lower Cretaceous age.

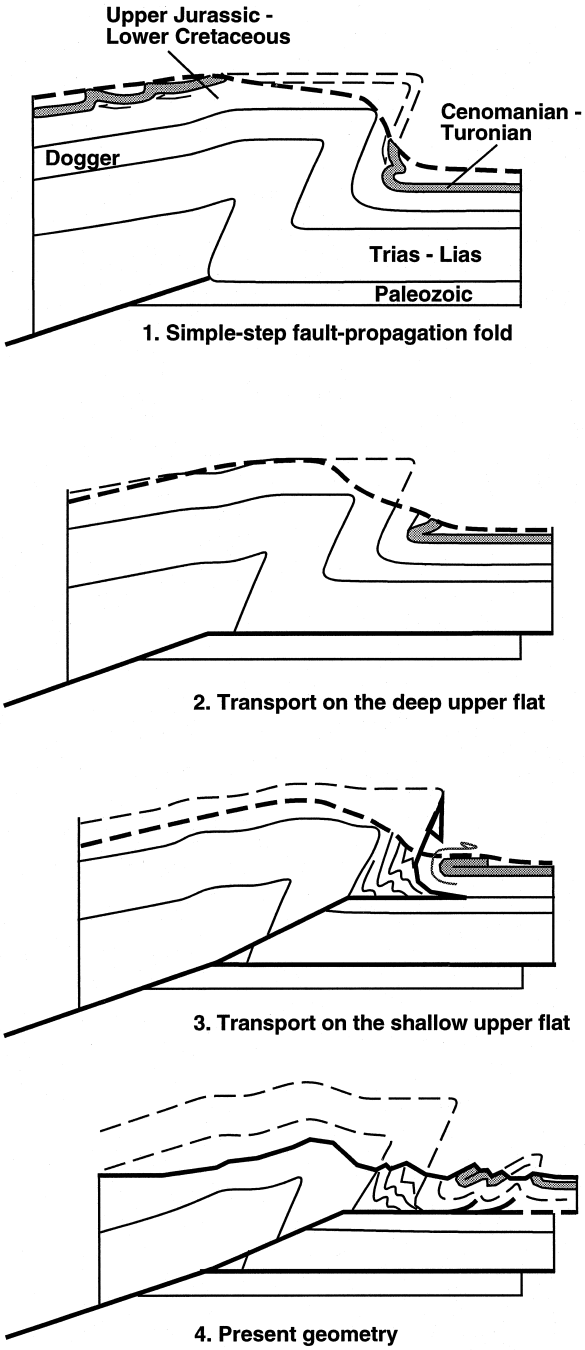

Fig. 2. A kinematic scenario for the growth of the Jebel Ta'bbast anticline modelled using the Ramp E.M. software (Mercier et al., 1997). At stages 1, 2 and 3 the erosion level is only indicative. The orientation of the cross-sections is NNW–SSE, the scale is 2.1 cm for 3 km.

De Sitter's proposal: the recumbent syncline had originated by collapse along the forelimb of the Jebel Ta'bbast anticline and was accentuated during its forward transport on an upper flat.

- In the Storti and Salvini model the slip acting on the lower flat is completely accommodated in the Jebel Ta'bbast anticline whereas field geology shows that, at two stages of the Neogene evolution, a part of this slip is transmitted forward to the frontal Tadighoust anticline (Saint Bezar et al., 1998) (Fig. 2).
- In the field, a disharmony exists between the Turonian limestone and the underlying red sandstone of Upper Jurassic–Lower Cretaceous age: Turonian beds alone are involved in the recumbent syncline whereas red beds are somewhere overturned but never recumbent. Additionally, the recumbent syncline is separated from the Jebel Ta'bbast forelimb by a stack of chevron folds involving the layered Dogger sequence (Saint Bezar et al., 1998, fig. 6a). This stack, developed as a consequence of a transport of the Jebel Ta'bbast on the shallow flat mentioned above, acted as a wedge decoupling the above lying strata from their substratum. The recumbent syncline which is situated at the wedge front is, consequently, linked to a late stage evolution (Fig. 2) and not to the simple-step propagation of the Jebel Ta'bbast ramp as proposed by Storti and Salvini.

References

Boyer, S.E., 1986. Styles of folding within thrust sheets: examples from the Appalachian and Rocky mountains of the USA and Canada. Journal of Structural Geology 8, 325–339.

De Sitter, L.U., 1956. Structural Geology. McGraw-Hill, London.

Harrison, J.V., Falcon, N.L., 1934. Collapse structures. Geological Magazine 71, 529–539.

Mercier, E., Outtani, F., Frizon de Lamotte, D., 1997. Late evolution of fault-propagation folds: principles and example. Journal of Structural Geology 19, 185–193.

Ramsay, J.G., 1974. Development of chevron folds. Geological Society of America Bulletin 85, 1584–1596.

Rowan, M.G., 1993. Structural geometry of the Widhorn Nappe between Aar massif and the Brienzer See. Eclogae Geologicae Helvetiae 86, 87–119.

Saint Bezar, B., Frizon de Lamotte, D., Morel, J.L., Mercier, E., 1998. Kinematics of large scale tip line folds from the High Atlas thrust belt, Morocco. Journal of Structural Geology 20, 999–1011.

Storti, F., Salvini, F., 1996. Progressive rollover fault-propagation folding: a possible kinematic mechanism to generate regional scale recumbent folds in shallow foreland belts. American Association of Petroleum Geologists Bulletin 80, 174–193.