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The Relationship Between Tectonic Stylolites and Fold Morphology in Limestones of the "Croatica Deposits" (Croatia)

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Abstract

Stylolites associated with axial plane fractures occur in Lower Pannonian clayey limestones (the "Croatica Deposits") from the "Hampovica 6" deep exploration well. A genetic link has been observed between the origin of fractures and the process of stylolitization. Strong tectonic deformations are present which have been formed under the influence of reverse bed faulting. Deformation is pronounced in the shape of folded marl layers along with the creation of thick cleavage (0.3-0.5 cm). Along the fractures of axial plane cleavage, microlithons are separated and moved apart for similar values (2-5 mm) forming a moderate synform. Stylolites are formed in the last phase of structure shaping when the effects of the local compressional stress have weakened under the influence of which the breaking off and folding of marl layers occurred. Their strike cut the bedding and older fracture systems.

1. INTRODUCTION

In general, tectonic stylolites are not parallel to bedding and are formed as a result of the spatial tectonic compression of carbonate rocks. They characterize deformed carbonates of orogenic regions. Under the influence of tectonic compression, stylolites can be shaped along the present fractured discontinuities or as independently formed systems of stylolite sutures (RAILSBACK & ANDREWS, 1995). Either case, it is clear that the stylolite columns are oriented parallel to the main stress direction ($\sigma 1$). If the stylolite columns are not perpendicular to the stylolite suture plane, it means that stylolites have been shaped along the discontinuity plane that already existed (DEAN et al., 1988). In Jurassic limestone foothills of the Pyrenees PETIT & MATTAUR (1995) have determined two phases of tectonic stylolite occurrences. The first generation of stylolites appears in the plane perpendicular to the main stress ($\sigma 1$) whereas the second generation is connected to extension of left transcurrent fault.

This paper describes the tectonic deformational sequence which led to formational processes of tectonic stylolites in Pannonian clayey limestones ("Croatica Deposits"). The genetic link between faults and fracture creation and the process of stylolitization under the influence of local stress with the same orientation has been noticed.

Stylolites often occur in limestones and marls, either a) parallel to, or b) at an angle relative to the bedding plane. The first stylolite type, parallel to beds has been formed as a result of gravity and sediment compaction. The initial thickness of sediments can be reduced by gravitational processes up to 20-30% (TIŠLJAR, 1978). In this case, stylolitic sutures are generally parallel to bedding planes and columns are initially oriented perpendicular to bedding. Stylolites oriented at an angle relative to bedding, have been created under the influence of oriented stress during tectonic processes. In the case of tectonic stylolites the columns are oriented parallel to stress direction.

2. DISCUSSION AND RESULTS

Tectonic interpretation of stylolite occurrences in the exploration well core of Hampovica-6 (Fig. 1) is based on analysis of the relationship between stylolites and present fracture systems. In the 10 cm diameter well core, clayey limestones of the "Croatica Deposits" show a set of normal faults along which the bedded limestones have been separated in a step-like manner. Noted occurrences of stylolites cut by their strike limestone beds together with the faults.

2.1. The genesis of fracture systems

The thick fracture system of small dimensions normal faults (Fig.1), where single faults are 3-5 mm apart, has a "domino-like" structure. It has been created during folding under the influence of reverse shift between two parallel reverse faults (Fig. 2), like a typical Riedel sliding system of fractures (R') which occurred at an angle of 75° to the sliding plane.

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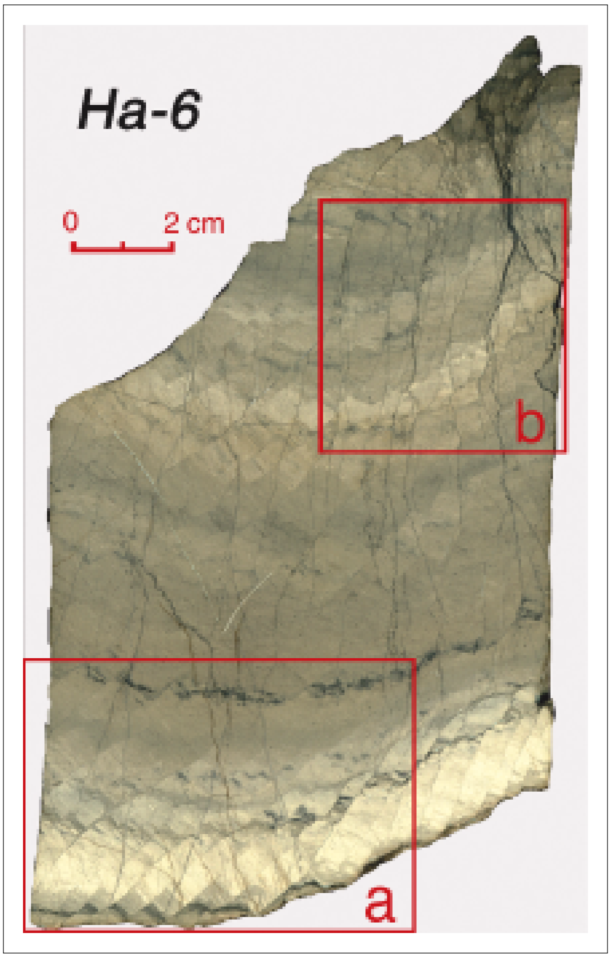

Fig. 1 The core sample of deep exploration well Hampovica-6; detail a) shows a fracture system of normal faults, whereas the detail b) shows the stylolites, cleavages and beds relation.

The successive development of the structure (Fig. 2a), show that the set of thick sliding fractures has been formed between two reverse faults in the limestones of Hampovica-6 well at the distance of approximately 5 mm. If stress and sliding activities along the reverse faults (Fig. 2, b-d) continues further, the fracture planes (R') progressively internally rotate around the horizontal axis. In the final structural act, the fracture planes are rotated from the initial angle of 75° to the sliding plane of reverse fault for another 65°. During the rotation the fracture has been folded and has obtained a sigmoid shape, while the cut-off limestone beds along the cleavage have drifted apart by various low values.

In Fig. 3, 3-5 mm wide lithons are observed that have been moved apart along the thick fractures R'. The envelope of such separated microlithons delineate a gentle synform. Along the contact with the fracture the beds have been concavely folded as a conseqence of sliding and migration of separated lithons of limestone beds into the apical parts of the synform.

At the fracture planes (R') the records of linear elements that occurre (***a***-lineation) in the shape of striae have been formed due to sliding along the fractures.

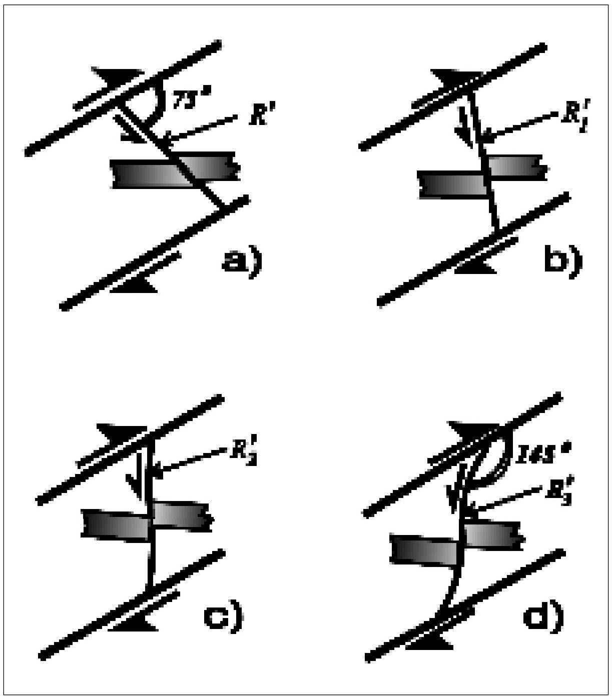

Fig. 2 The succession of sigmoid fractures formation and spreading of limestone beds between two reverse faults.

Taking into account that the well Hampovica-6 is vertically positioned, as well as the fact that ***a***-lineation lies in the plane parallel to the well axes, it can be concluded that the main basic stress (σ1), during deformation processes, occurred approximately horizontally. The middle stress axis (σ2) is also horizontal and perpendicular to the well axis, while σ3 is placed approximately along its axis.

2.2. The genesis of stylolites

Stylolites observed in the Hampovica-6 well, have been shaped in a stress field which acted homogeneously over a lengthy period of time without reactivating older, pre-existing fracture systems. Along strike, they cut off all planes of different discontinuities, bedding, and fractures (R') from the axial plane. This shows that stylolites have been created after the final tectonic configuration of the structures present in the well. Namely, two sets of different deformations indicate two events of the same compression that is localized only in the part of limestone of this well. The fact is that in the other examined rock samples from this well, coming from more shallow and deeper parts than this interval, neither the stylolitization nor the significant structural deformations have been observed.

Envelopes of stylolite planes (Figs. 1 and 4) mainly follow the well axis and in relation to the present synform are placed into its axial plane. The axis of stylolite columns are horizontally oriented which implies that the strongest main stress (σ1) that led to its formation, acted nearly horizontally, namely, perpendicular to the

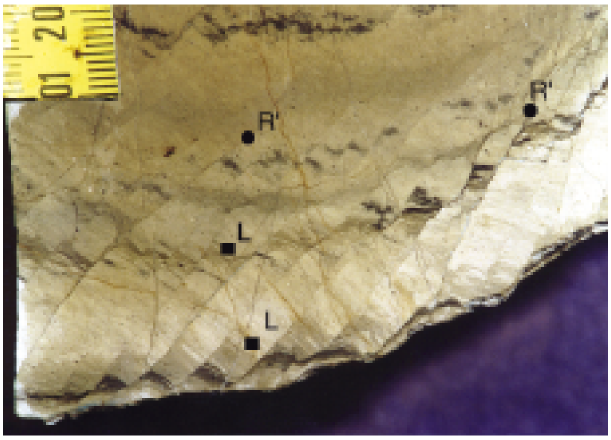

Fig. 3 Detail (a) from Fig. 1: 3-5 mm wide lithons (L) have been observed which delineate, by moving apart by the normal faults (R'), the shape of gentle synform.

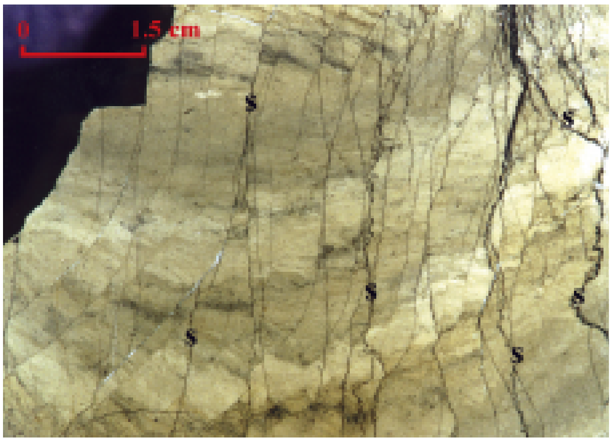

Fig. 4 Detail (b) from Fig. 1: Reduction of beds along the stylolite suture (S) with the amplitude of 1-2 mm.

well axis. As stylolites by their strike follow none of the previously shaped discontinuity planes, it can be concluded that the stress affected previously tectonically shaped and solidified rock.

Figure 4 shows some stylolite thickness enhancement relative to other parts of the Hampovica-6 well sample. (Fig. 1). The reduction of limestone beds has been observed along the stylolite suture during the compression and gradual dissolution. The dissolved parts of microlithon beds from left and right side of suture do not have the same dimensions, which is visible in the lower and central part of the Fig. 1. As a result of dissolution along some stylolite suture, the clayey limestones were compressed for 2-5 mm. The amplitudes of stylolite sutures are up to 1 mm, whereas the sutures are filled with clayey material that has remained as insoluble rock residue.

3. CONCLUSION

Two phases of tectonic deformation, directly following one after another can be distinguished on the basis of analysis of fracture systems morphology and the described occurrences of stylolites in the deep exploration well Hampovica-6. The deformations described were created as a result of stress, the main axis ($\sigma 1$) of which acts continuously horizontally, but with different final effects of tectonic deformations.

(1) In the first phase fracture systems were created which are the outcome of reverse movements. Reverse faults are shaped under the influence of stress $\sigma 1$ on nearly horizontal line. The shifts along the reverse faults brought to sigmoid folding of accompanying fractures and spacing off of limestone beds for nearly the same values, forming a synform and "domino" structure.

(2) In the second phase of the same stress activity, tectonic stylolites appear without occurrences of tectonic transport together with present discontinuity planes. The strike of the envelopes of stylolitic sutures is placed in the axial plane of previously shaped synform. The size of main stress ($\sigma 1$) in this phase is considerably diminished. The stress acted continuously over a lengthy period of time, facilitating the dissolution of rock content along the stylolite suture.

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