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The kinematics of deformation of the Kenerong Leucogranite and its enclaves at Renyok waterfall, Jeli, Kelantan

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Abstract: The Late Cretaceous Kenerong Leucogranite, a component of the Stong Complex exposed near TNB mini power station, at Renyok waterfall, Jeli, Kelantan consists of a sequence of leucogranite vein and metasedimentary enclaves. Here, varieties of structures developed in both rock types. Structural studies indicate the rocks here had undergone at least four phase of deformation. It is interpreted that the first deformation (D_1) with the compression from ESE, which was responsible in the development of foliation and reverse faults was related to the regional stress system during the Late Cretaceous time. The second and third deformation (D_2 and D_3) with the compression from NE sector, that was related to the formation of lateral faults system, pinch-and-swell, boudinage, drag folds and small-scale kink folds might be related to the stress system that were generated by the emplacement of the younger granite in the vicinity. The fourth deformation (D_4), which was responsible for the normal faulting by the reactivation of the preexisting faults, was probably related to the relaxation period after the granite intrusion of the area.

Abstrak: Leukogranit Kenerong yang berusia Kapur Lewat, satu komponen daripada Kompleks Stong yang tersingkap berhampiran stesen kuasa mini TNB di Air Terjun Sungai Renyok, Jeli Kelantan terdiri daripada satu turutan telerang leukogranit dan metasidimen. Di sini terdapat kepelbagaian structure telah terbentuk dalam kedua-dua jenis batuan, Kajian struktur menunjukkan batuan telah mengalami sekurang-kurangnya empat fasa canggan. Ditafsirkan bahawa canggaan pertama (D_1) dengan arah mampatan dari UTL yang bertanggung jawab dalam pembentukan foliasi dan sesar songsang adalah berkaitan dengan system tegasan rantau semasa Kapur Lewat. Canggaan kedua dan ketiga (D_2 dan D_3) dengan mampatan daripada sector timur laut (TL) yang berkaitan dengan pembentukan system sesar mendatar, ramping-dan-ampul, boudinag, lipatan seret dan lipatan kercau berskala kecil boleh dikaitkan dengan system tegasan yang diakibatkan oleh penempatan granit yang lebih muda di kawasan berhampiran. Canggan ke-empat (D_4) yang bertanggung jawab dalam pembentukan sesar normal secara pengaktifan semula satah sesar yang sudah sedia ada mungkin berkaitan dengan tempoh pelepasan selepas rejahan granit di kawasan ini.

INTRODUCTION

The Kenerong Leucogranite is a component of the Stong Complex (Singh, *et al.*, 1984). This complex consists of plutonic and high-grade metamorphic rocks, situated in the northwestern parts of Kelantan. In a brief account of this Complex, Singh (1963) recognized that this Complex consist of granitic core associated with enclaves of metasediments. Later, MacDonald (1967) regarded the granite of this Complex as an easterly protrusion of Main Range Granite but Huthison (1973) interpreted the granitic elements of this complex was distinct from the Main Range batholith. In a reassessment of this complex, Singh *et al.* (1984), considered the stong Complex consists of three components, in order of decreasing age was named as Berangkat Tonalite, Kenerong Leucogranite and Noring Granite.

The Kenerong Leucogranite was named after the Sungai Kenerong (MacDonald, 1967). This rock component is well exposed at Sungai Renyok, near TNB mini power station (Fig. 1). Here, the country rock is sandwiched between the leucogranite veins forming metasedimentary enclaves. Singh *et al.* (1984) interpreted that at least the last parts of the Stong Complex intrusion took place in Late Cretaceous time, while the age of earlier phase is Triassic to Late Cretaceous. This paper will deal with the structures of the Kenerong Leucogranite and its enclaves, based on observations and data collections during a detailed structural mapping of a continuous and very good outcrop at Sungai Renyok, near TNB mini power station. This outcrop was considered as very interesting, unique and should be preserve as one of the geological heritage in Kelantan (Tanot *et al.*, 2001). From field relationship of all the structures observed and the indications of the slip direction as shown on the shear planes (mainly fault planes), the kinematics of deformation experienced by this rock component is proposed.

THE KENERONG LEUCOGRANITE

The Kenerong Leocogranite consists of a sequence of veins of fine to medium grained leucogranite, biotite granite, pegmatite and aplite. The veins are predominatly leucogranite and some other lithological variation particularly in biotite content, but generally light colour, ranging from a few cm to 5 m wide. The country rocks, which now form the metasedimentary enclaves, are considered to be Permo-Carboniferous to Early Triassic, originated probably from the Gua Musang Formation. The enclaves comprise of metapelites, meta-arenites and impure to pure marble and amphibolites. The calcareous sedimentary rocks had been metamorphous to calc-silicate hornfelses. However, at Sungai Renyok outcrop, no marble and amphibolites are found.

Varieties of structures developed in both leucogranite vein and metasedimentary enclaves are very striking as had been described by Singh *et al.* (1984).

STRUCTURAL OBSERVATIONS

The structure of the Kenerong Leucogranite outcrop at Sungai Renyok is illustrated in Figure 2. At this locality, there is at least three generations of vein can be identified. Most of the veins are concordance with the metasedimentary enclaves. However, a number of thinner veins, which were considered as late stage intrusion or as a result of metamorphism, cut the host rocks at acute angle. The enclaves and the wider veins (up to 5 m) are well foliated, oriented parallel or almost parallel to the contact between the veins and the host rock (Fig. 3).

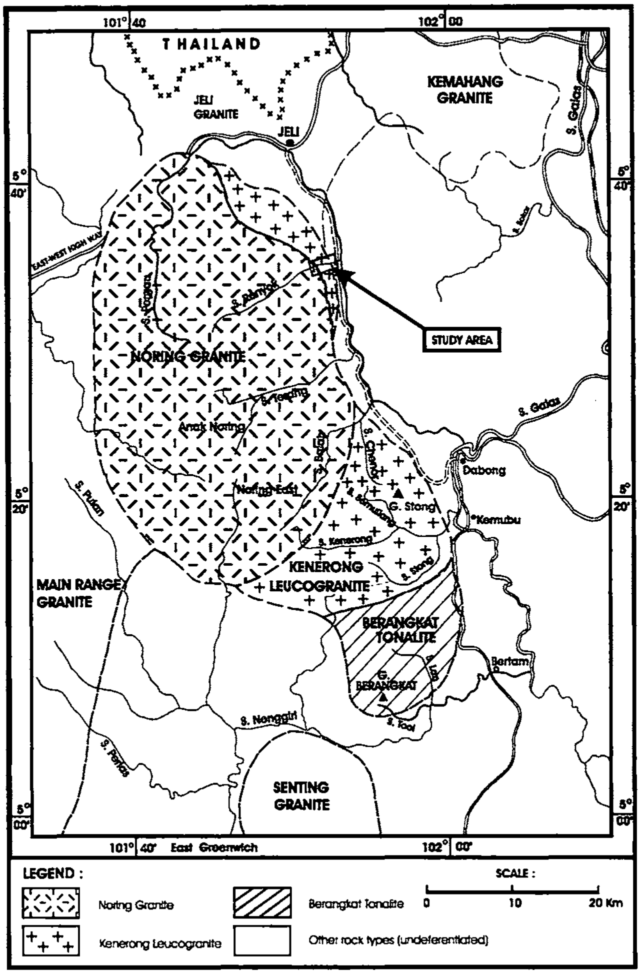

Figure 1. Location map of the Stong complex and the location of the study area at Renyok waterfall, Jeli Kelantan.

Evidence of shearing can be seen on the bedding planes of metapelites and meta-arenites or on the plane of the veins along the contact with metasediments, producing slickensides with oblique striations. Most of the striation on the bedding of metapelites and meta-arenites (Fig. 4), indicate reverse-sinistral movements, while on the plane of the veins surface show normal-dextral movement (Fig. 5).

The contact between the sheared and well foliated igneous and country rocks were cut and displaced by a conjugate lateral faults system aligning in NNE and ESE directions. Apart from faults, conjugate joints system were also developed and filled-up by the late granitic material (Fig. 6). The late stage granitic material also filled some of the NNE faults, producing third generation veins. In the overlapping area, where two faults ended, Z-shaped sigmoidal veins were developed as expected, and in agreement with the dextral movement along the fault. Near the end of a NNE lateral fault, second order splay faults with same sense of movement were developed; with bearing differ about 15 degrees from the major fault (Fig. 7). The conjugate lateral faults and their splay are displaced by approximately N-S lateral faults.

Some of the thin leucogranite veins (several cm up to 50 cm wide) had been deformed into pinch and swell or boudinage (Figs. 6 and 8). The boudinage bodies show some degree of fracturing and cut by several direction of faults and tension cracks which aligned almost parallel to the stream flow (Fig. 9). As a result of shearing, same parts of the inter-layering metasediments and vein were folded into drag folds (Fig. 10). Shearing was also responsible in the transformation of the foliations in the wide veins into of the kink-bands and crenulations folds (Fig. 7).

STRUCTURAL ANALYSIS

The structural data (strikes and dips and the directions and sense of movement) of the shear planes and faults developed during each period of deformation were analysed using program STRESS 3.1. The result of the analysis is shown in Figure 11 (A, B, C, D and E), which indicates the directions of the principal stress ($\sigma 1$, $\sigma 2$ and $\sigma 3$) as well as the stress field at the time of each deformation period. As it is shown in this figure, the structures developed during D_1, D_2 (A and B) and D_3 were related to compression while

Table 1. Plunge and plunge direction of s1, s2 and s3 related to each deformation phase.

No.	Deformation phase	$\sigma 1$	$\sigma 2$	$\sigma 3$	Remarks
1.	1st. deformation (D_1)	1°, N282°E	13°, N35° E	55°, N 193° E	Figure 11A
2.	2nd Deformation (D_{2A})	9°, N79°E	66°, N327°E	22°, N173°E	Figure 11B
3.	2nd Deformation (D_{2B})	30°, N75°E	59°, N234°E	9°, N339°E	Figure 11C
4.	3rd Deformation (D_3)	26°, N209°E	33°, N101°E	47°, N328°E	Figure 11D
5.	4th Deformation (D_4)	63°, N156°E	27°, N337°E	1°, N247°E	Figure 11E

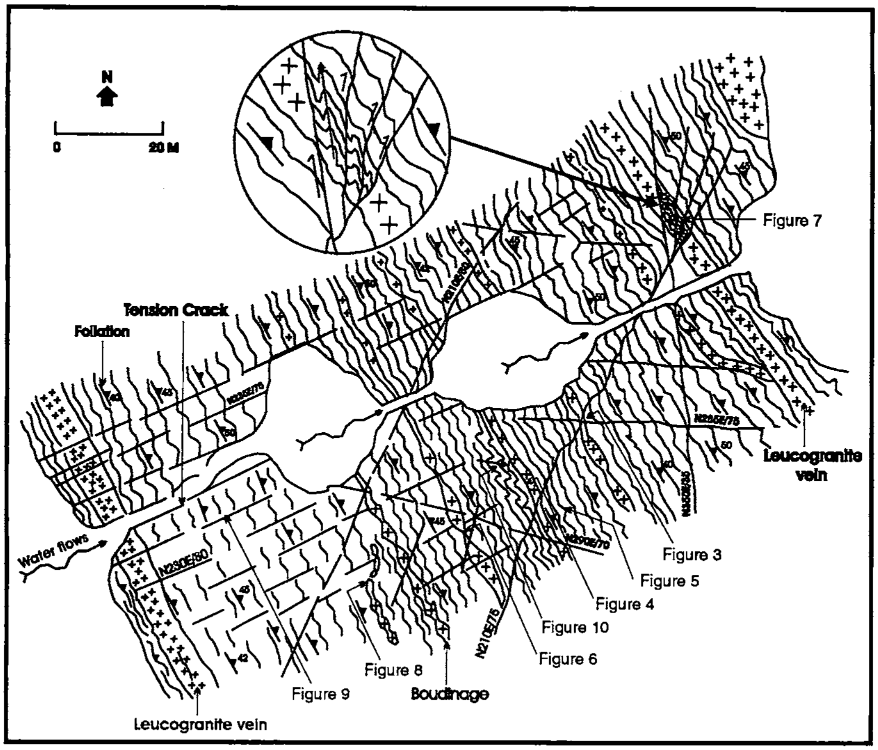

Figure 2. Structural map of the Kenerong Leucogranite and its enclave at Renyok waterfall, Jeli, Kelantan.

D_4 was related to tension. Figure 12 indicates the general orientation of all the structures developed during each period of deformation, found at this locality. In this figure, the average orientation of Faults and cracks are plotted as planes while boudinages, drag folds and kink folds are plotted as lineations. The figure also shows the corresponding maximum principal stresses ($\sigma 1$) related to each for deformation whenever it was dominated by compression and minimum principal stress ($\sigma 3$) for deformation dominated by tension. Table 1 summarized the plunge and plunge directions of the maximum principal stress ($\sigma 1$), intermediate principal stress ($\sigma 2$) and minimum principal stress ($\sigma 3$), related to each deformation phase of the area.

KINEMATICS AND SEQUENCE OF DEFORMATIONS

Based on the interrelationships (cross-cutting and displacement) between all the structures present at this outcrop as illustrated in the photographs and Figure 2, the sequence of events and the kinematics of deformations of this rocks association are interpreted as follows;

a. The intrusion of various sizes of leucogranite veins (up to 5 m wide) into the country rocks, concordance or slightly discordance to the strata. The thinner veins had undergone faster cooling to become more brittle while the thicker veins were slower and keeping slightly more ductile at the time this rocks experienced the first deformation.
b. The first deformation (D_1) produced reverse-left slip faults. Most of the faults related to this deformation followed the contact between the metasediments and the veins with general strike and dip (340°/50°), producing slickensides and striations and on the bedding plane of the metasediment. Along these faults, some narrow shear zones were also developed. As a result of this deformation, foliation were formed both in metasedimentary host rocks as well as in the wider veins which were slightly ductile at the time of deformation. At the same time, boudinage were developed in the thinner veins. During the relaxation of the first deformation, the thinner and slightly discordance second-generation veins intruded, some of them filled up the space between the foliation within the first generation veins.
c. The second deformation (D_{2A}) took place when the rocks became more brittle, forming conjugate lateral faults (The general strike and dip of the dextral faults is 220°/80° and the sinistral faults is 290°/70°), cut and displaced the foliation as well as the boudinage. D2 was also responsible in the development of the pinch-and-swell and boudinage structures in the second-generation veins. Near one end of the NE oriented dextral conjugate faults, splay or subsidiary faults were formed (D_{2B}), with average strike and dip is 250°/80°, indicating same sense of movement. In is interpreted that the movement on the splay faults was responsible in the developments of the small-scale kink- folds within the first generation foliated veins. Some of the

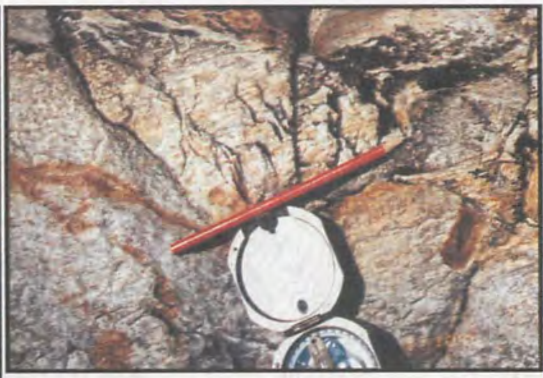

Figure 4. Striations on the bedding plane of the metasidements, showing reverse-left slip movement related to the first period of deformation.

Figure 3. Metasediments (enclave) intruded by Kenerong Leucogranite. Photo direction to NE.

Figure 5. The striations and plucking steps, showing the normal slip as a result of the 4th deformation phase. Photo direction to west.

Figure 6. Boudinage of the leucogranite veins as a result of the 2nd deformation, cut by conjugate structure and NE direction tension cracks. Photo direction to SW.

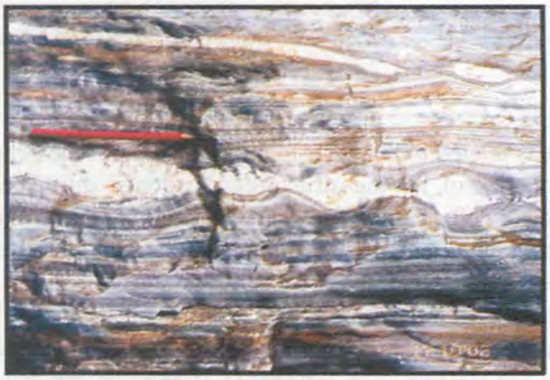

Figure 8. A slightly discordant vein has been transformed to boudinage by the 2nd period of deformation. Photo direction to SW.

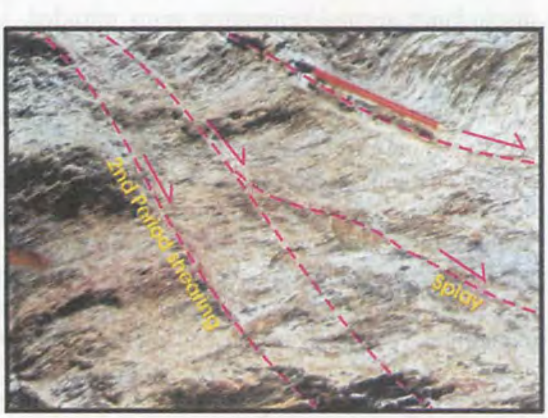

Figure 7. Foliated leucogranite vein displaced by the 2nd period shearing and splay faults. Kink folds developed in response to the movements along the splay faults. Photo direction to SW.

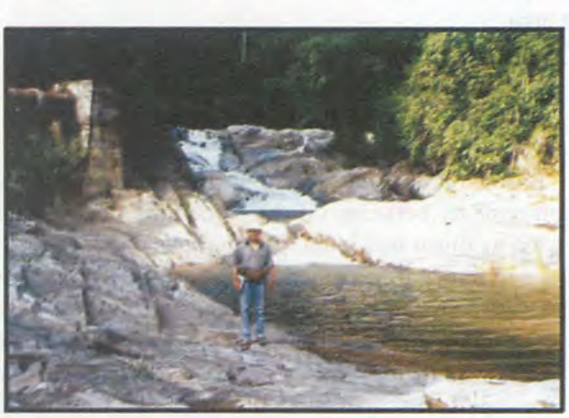

Figure 9. Stream water flows along the tension cracks resulted from the last episode of deformation of this rock unit. Photo direction to SW.

Figure 10. Leucogranite veins interfolded with metasediments to form drag folds, plunging towards N305°E. Photo direction to NE.

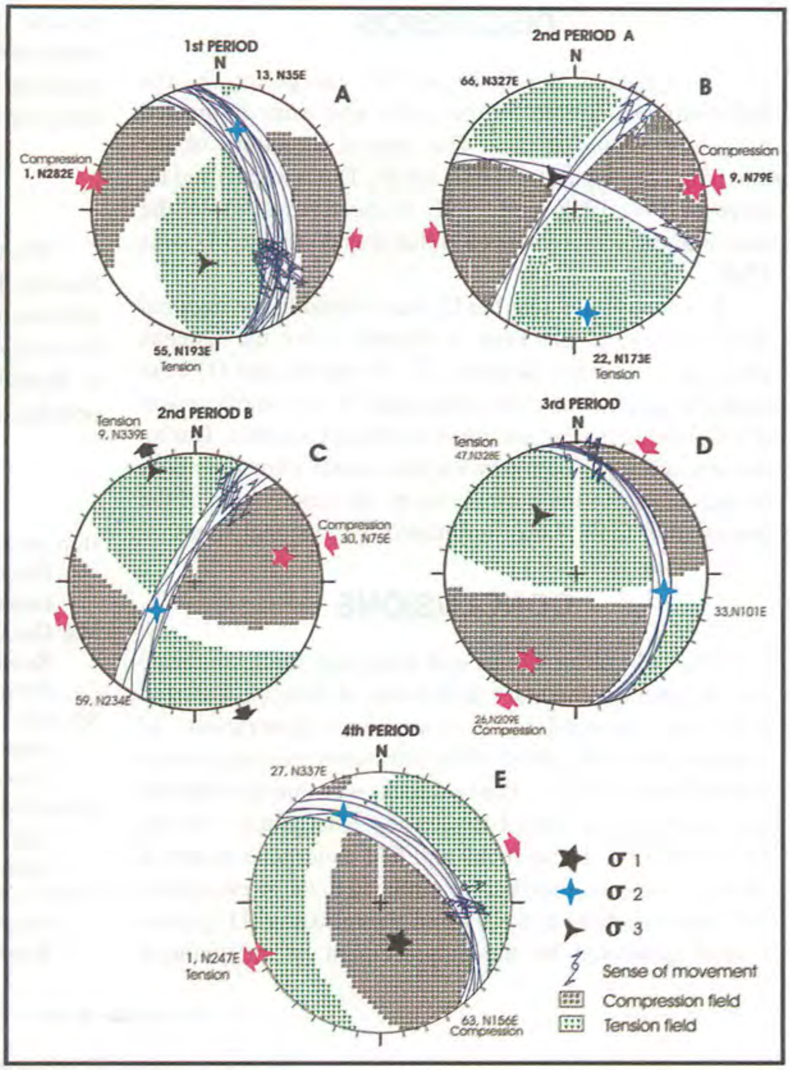

Figure 11. Palaeostresses and stress field related to the deformation of the Kenerong Leucogranite at Sungai Renyok, Jeli, Kelantan. A) First period; B) Second period A; C) Second period B; D) Third period; and E) Fourth period.

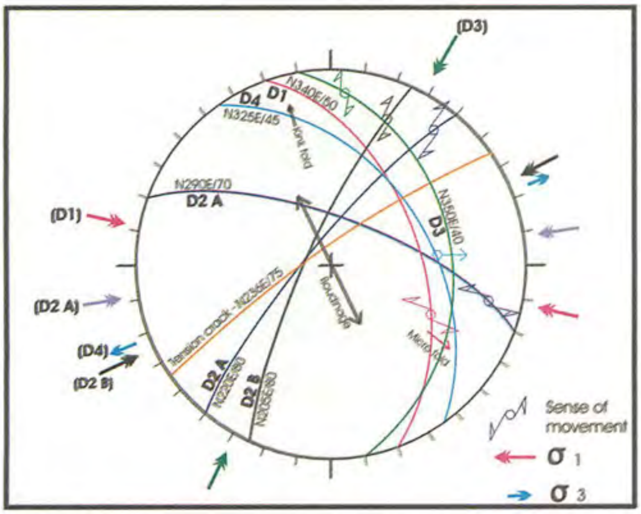

Figure 12. Structural elements of the Kenerong Leucogranite at Sungai Renyok. D1, D2A, D2B, D3 – ductile; D4 – brittle.

fractures in both metasediments and veins seem to be related to this phase of deformation.

d. All the structures developed during D_1 and D_2 (D_{2A} and D_{2B}) were displaced by almost north-south right lateral faults, which are considered as a result of third deformation (D_3). Shearing related to this deformation was responsible in the folding of the inter-layered veins and metasediments to produce drag folds, plunging moderately towards SE.

e. Normal faulting relates to the forth deformation (D_4) took place along the contact between the veins and the metasediments almost in the same direction as the reverse faults that was produced during the first deformation (D_1).

f. The opening of the tension cracks along which the stream water flows are considered as the last episode of deformation in this area, probably the reactivation of the tension fractures that were developed during the second deformation (D_2).

DISCUSSION

As it is indicates in Figure 11, except for D_4, the deformations suffered by this rocks unit were dominated by compressional stress. The general directions of the maximum principal stress ($\sigma1$) for D_1, D_2 (A and B) and D_3 were WNW, ENE and NNE respectively, while the minimum principal stress ($\sigma3$) that was dominated D_4 was ENE.

It is interpreted that the D_1 was related to the regional stress system at the time or slightly after the igneous intrusion in Cretaceous time. D_2 (A and B) and D_3 were probably related the stress generated by the emplacement of the younger Noring granite of the Stong Complex. During the relaxation period following the granite intrusion might be the reason for the normal slip by the reactivation of the pre-existing fault plane, dominated by tensional stress.

CONCLUSIONS

The field observations and structural studies indicate that the metasedimentary host rocks at Renyok waterfall had been intruded by at least three generations of leucogranite veins. Most of the intrusions are concordance with the metasediment. The host rocks were metamorphosed and partly sandwiched between the leucogranit veins to form enclaves. These rocks unit had undergone at least 4 phases of deformation that were related to the stress system in Cretaceous time at the time of the intrusion (D_1), stress system generated by the emplacement of the younger granitic rock unit nearby (D_2 and D_3) and the tensional stress developed during relaxation period, after the major intrusion (D_4). The formation of the tension cracks is interpreted as the last deformation suffered by the area.

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