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OBSERVATIONS ON THE SHEAR-FRACTURES OF THE MARBLES OF THE NORTH PELAGONIAN ZONE

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Abstract: *In this paper are studied the phenomenon of shear-fractures of marbles-dolomites of the North Pelagonian zone along a strike-slip fault at the area of mountain Voras (Greek Macedonia). It also takes place a statistical elaboration of measurements conserning microfaults and joints on the Triassic-Jurassic marbles as well as on the Paleozoic crystalline basement and the Upper Cretaceous coverage, mainly at the fault area. The differences among the fractures in the different formations are found out, while conclusions about the effect of the fault on the fracturing of the marbles are reached. Finally the succesive tectonic phaces, which caused the fractures in the North Pelagonian zone, are determined.*

A. SITUATION

The tectonic observations to which we are refered took place in the Eastern margin of North Pelagonian zone and specificly at the area of the villages Orma and Kato Loutraki belonging to the province of Pella (Macedonia).

B. GEOLOGICAL STRUCTURE OF THE AREA

The Eastern part of the North Pelagonian zone consists of the Paleozoic crystalline basement, the Triassic-Jurassic carbonate series and the Upper Cretaceous coverage (J. MERCIER 1968).

After the geological surveying of this part of the Pelagonian zone (D. MOUNTRAKIS 1976) the crystalline basement consists of gneisses, mica schists and amphibolites. The carbonate series consists of marbles, crystalline limestones and dolomites. The Upper Cretaceous coverage has as a first transgressive bed a microbressic limestone of Up-

per Santonian-Campanian age, then follows a Maestrichtian limestone and a final Cretaceous flysch.

The eastern boundary of the Pelagonian zone - contact with the zone of Almopia - is found at the area of the villages Orma and Kato Loutraki (Fig. 1).

The formations of the Almopian zone at this area are a metamorphic sedimentary series of Upper Jurassic age, the ophiolitic sequence, a small occurence of Lower Cretaceous limestone and the transgressive series of the Upper Cretaceous. The Almopian rocks as tectonic scales (écailles) overthrust to the West on the Pelagonian zone.

C. TECTONIC ELEMENTS OF THE AREA

The general direction of the beds, both of the Pelagonian and the Almopian zones, are at this area NW-SE (about 130°) and the dip 45°-70° NE.

The geological structure of the area has been strongly affected by the action of a long strike-slip fault (The fault of Kato Loutraki). This is what we know about this fault (D. MOUNTRAKIS 1976).

— Its direction is about 70°.

— It is expanded in both zones, the Almopian and the Pelagonian.

— It represents a pre - Upper Cretaceous tectonic fact, possibly connected with the Upper Jurassic - Lower Cretaceous orogenic period.

— It was re-activated during the after-Cretaceous tectonic phases.

— Its action has caused a horizontal displacement of the formations and the boundary of the two zones.

It is known that the U. Jurassic - L. Cretaceous has been an orogenic period of the Internal Hellenic Zones, during which the Triassic-Jurassic carbonate series of the Pelagonian zone was folded according to «tectonique de revêtement».

More recent investigations in the North Pelagonian zone (P. VERGELY 1976) proved that during the U. Jurassic - L. Cretaceous two foldings took place: A 1est folfing at the Upper Jurassic (pre-Tithonian) with direction axis 155° which was symmetamorphic for all the pre-cretaceous formations; and a 2nd one at the Lower Cretaceous (pre-Aptian) with direction of folds axis 0°-30°.

Considering these more recent aspects we assure that the direction of the Kato Loutraki fault (70°) is about vertical on the direction of axis of the 1est folding. This fact make more specific the connection

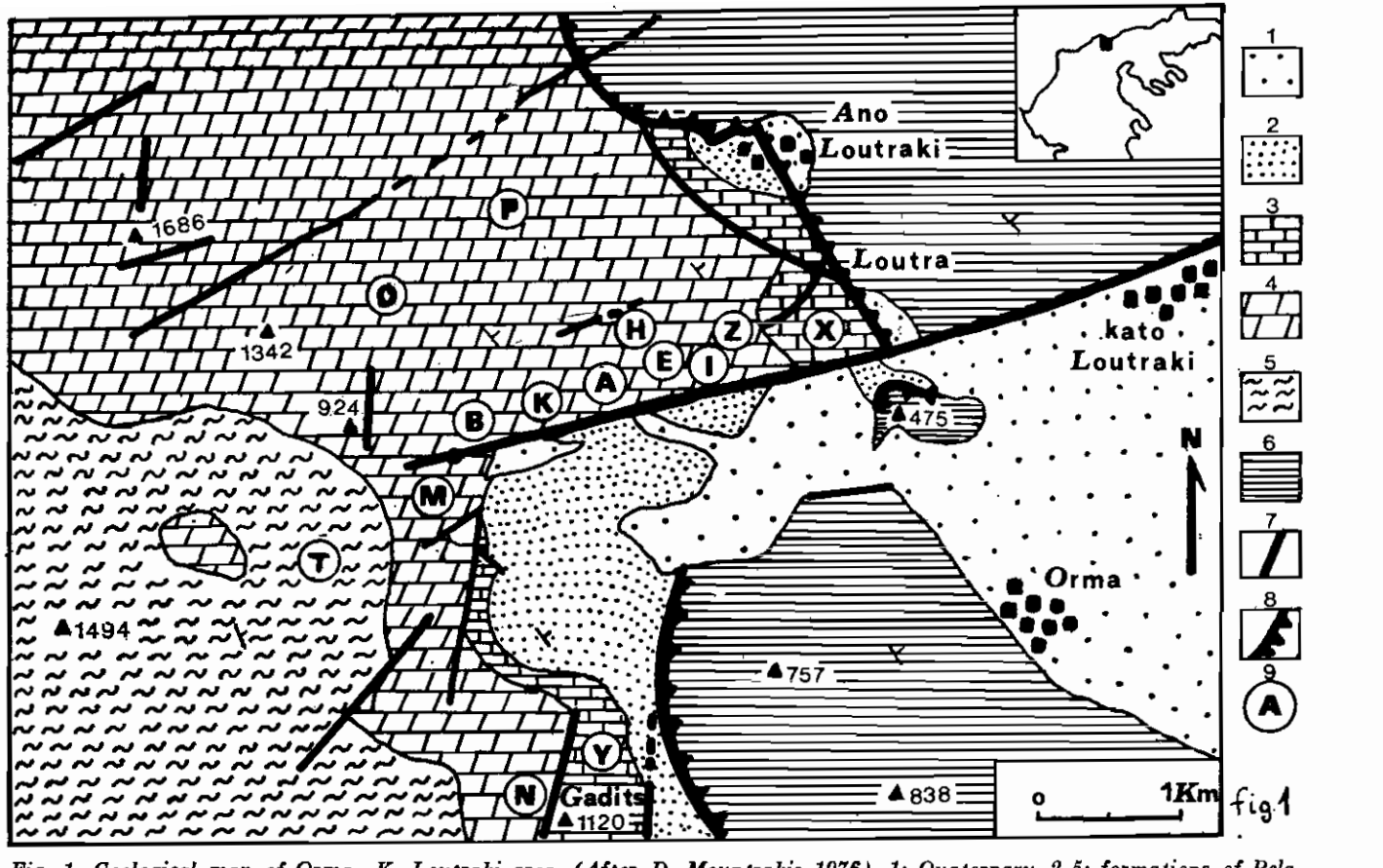

Fig. 1. Geological map of Orma - K. Loutraki area. (After D. Mountrakis 1976). 1: Quaternary, 2-5: formations of Pelagonian zone (2: Upper Maestrichtian flysch, 3: Upper Cretaceous limestones, 4: Triassic - Jurassic marbles and dolomites, 5: Paleozoic crystalline basement), 6: formations of Almopian zone, 7: fault, 8: boundary of Pelagonian and Almopian zones, 9: sampling points (joints - microfaults).

of this fault with the U. Jurassic - L. Cretaceous orogenic period and especially with the 1est folding phase. Combining our observations on the displacement of the formations of the two zones, as well as the bibliography (S. HILLS 1972, J. RAMSAY 1967), we characterize the Kato Loutraki fault as a cross, dextral strike-slip fault. connected with the Upper Jurassic (pre-Tithonian) folding.

The Pelagonian marbles - dolomites have undergone a strong mylonitisation and shear-fracturing particularly impressive along the Kato Loutraki fault, at a zone of about 1 km width (J. MERCIER 1968, D. MOUNTRAKIS 1976). The shear-fractures of the marbles were caused by a large number ol joints and microfaults, the frequency of which is in most situations more than 100 joints per meter.

These phenomenon while have strongly struck the Triassic-Jurassic marbles, have not affected the Upper Cretaceous limestones of the zone, found transgressively overlaid on the mylonitic marbles. This observation certifies the pre-transgressive (pre-U. Cretaceous) age of these tectonic phenomenon; moreover we had expressed the aspect that these, as well as the Kato Loutraki fault are connected with the U. Jurassic - L. Cretaceous orogenic period (D. MOUNTRAKIS 1976). However the exact period during which these tectonic phenomenon took place, the directions of the shear-fractures, as well as their connection with the other tectonic elements of the area have not been determined because of the large number of the microfaults and joints, demanding a lot of statistic measurements.

D. TECTONIC ANALYSIS OF JOINTS AND MICROFAULTS

For the solution of the pre-mentioned tectonic problems it is necessary to know if the shear-fracturing of the Pelagonian marbles has been caused in different stages, by many tectonic phasses. That is:

—During the U. Jurassic — L. Cretaceous foldings.

— During the action of the K. Loutraki fault.

— During the post-Cretaceous tectonic phases which affected the Pelagonian zone.

For this purpose we have made measurements of the directions of the joints-microfaults on the Triassic-Jurassic marbles, on the U. Cretaceous limestones and the crystalline basement, in order to find out the existing differences. These measurements, the statistical elaboration of which is illustrated in the roses of Figure 2, have taken place in the following situations of the Pelagonian formations:

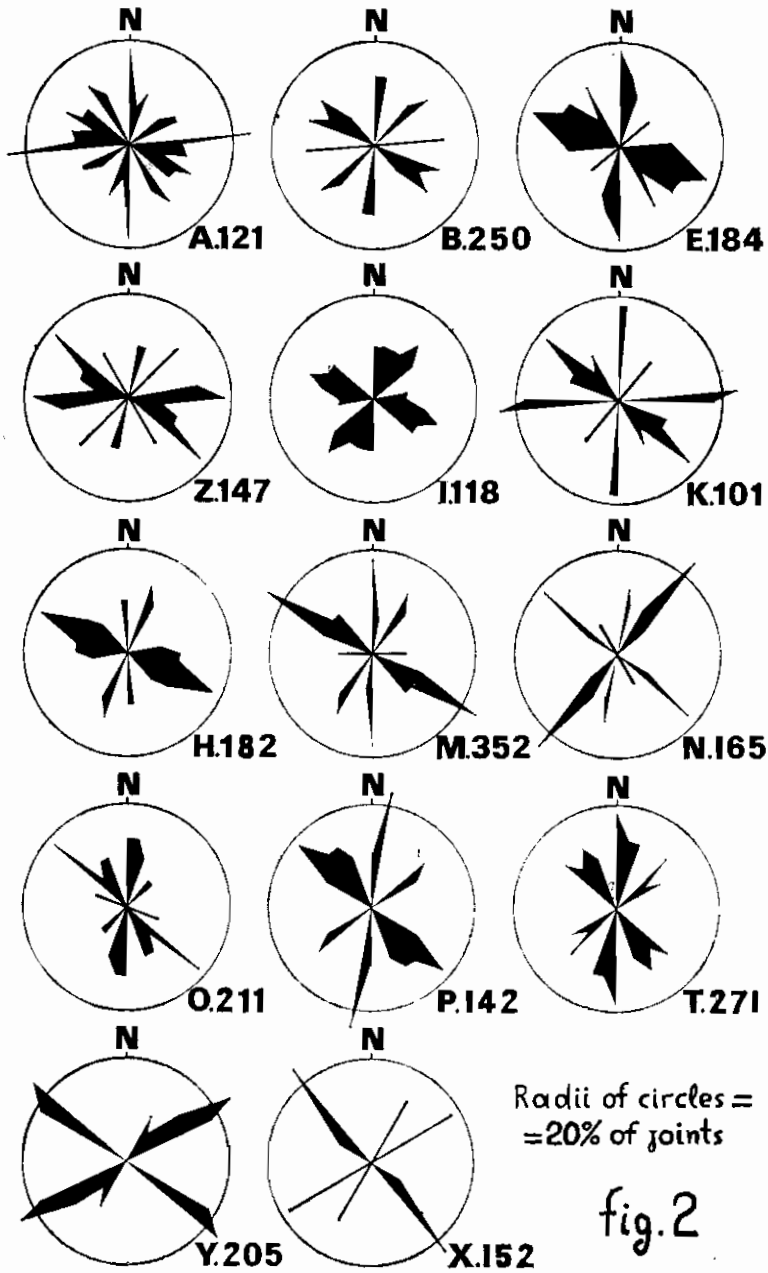

Fig. 2. Direction - roses of joints and microfaults. Sampling points on the geological map (fig. 1.). See also description in the text.

(1) On the Triassic - Jurassic marbles:

a) Along the Kato Loutraki fault, in the 1 km width zone where the shear-fracturing is particularly strong (roses A, B, E, Z, H, I, K, M Fig. 2).

b) At a long distance from the fault, on the North of it (roses O and P) and on the South of it (rose N), where the fault effect must be very small.

(2) On the crystalline basement, especially on the gneisses - mica schists being in contact with the marbles (rose T).

(3) On the Upper Cretaceous limestones:

a) At the area of mount Gadits where the effect caused by the action of K. Loutraki fault must be very small (rose Y).

b) At the area of Loutra near the fault (rose X) where the limestones have undergone a strong tectonism during the overthrust of the Almopian scales (écailles).

From the roses A, B, E, Z, H, I, K, M concerning the marbles of the case (1a) the following sets of joints are extracted:

1est set N-S up to NNE-SSW (0°-10°), the extreme values of which are in some places up to 30° (roses A, E, Z).

2nd set NE-SW (40°) with extreme values up to 60°.

3rd set ENE-WSW up to E-W (85°-90°).

4th set NW-SE having wide limits (100°-150°), expressed sometimes as a unique set with a large dispersion and sometimes as partly independent sets with directions 110°-115°, 120°-130° and 145°-150°.

From the roses N, O ans P of the marbles concerning the positions, which are away from the fault, the following sets are extracted:

1est set N-S up to NNE-SSW (0°-10°).

2nd set NE-SW (40°-50°).

3rd set NW-SE (130°).

4th set NW-SE (155°).

The last two sets appear on the rose P as unique (130°-155°).

The sets of the rose T, concerning the fractures of the crystalline basement (case 2), are:

1est set N-S up to NNE-SSW (0°-20°).

2nd set NE-SW (45°-60°).

3rd set NW-SE (130°-160°).

Finaly, the roses conserning the Upper Cretaceous limestones have given the following results:

For the case (3a), rose Y:

1est set NE-SW (45°-60°).
2nd set NW-SE (130°).

For the case (3b), rose X:

1est set NE-SW expressed by two maximum 30° and 60°.
2nd set NW-SE (135°).

We mention that from the measurements of the joints in the Almopian rocks, that were made at the same area K. Loutraki - Ormas being in contact with the Pelagonian zone (D. MOUNTRAKIS 1976), were found out two main sets of joints with directions NW-SE (120°-130°) and NE-SW (40°-50°) which we had connected with the Priabonian folding. We now find the same or about the same sets for the Upper Cretaceous sediments of the Pelagonian zone, which were undoudtedly struck by this phase. But the same two sets are found in all the roses of the marbles and the crystalline basement. This was expected, because the fracturing results of the Priabonian phase occured in all the pre-existing formations. But in the pre-Cretaceous rocks the set 130° is confused with previous fractures having similar directions, as it appears further.

On the marbles, as well as on the crystalline basement, appears in addition a set of joints with direction N-S up to NNE-SSW (0°-10°), which does not appear in the roses of the U. Cretaceous limestones. Therefore it represents a fracturing existing before the Upper Cretaceous. In the joints that were measured in the Upper Jurassic metamorphic series of Almopia zone (D. MOUNTRAKIS 1976), we had marked out a secondary set with direction 10°, which did not exist in the roses of the Upper Cretaceous sediments of Almopia. We had also suspected that this set was likely to represent a pre-U.Cretaceous tectonic phase. After the results of the investigations made by P.VERGELY (1976) this set (0°-10°) seems to be explained by the Lower Cretaceous folding, mentioned in the previous chapter, which caused folds with axis direction 0° up to 30°.

The wide limits (100°-150°) of the NW-SE set in the mylonitic zone of the marbles along the fault (case 1a), are particularly problematic, because they can't be justified only by a wide dispersion of the Priabonian fracturing with direction 130°. It is also problematic the existence in the same case (1a) of the ENE-WSW (85°) set, which is not found in the crystalline basement, the U. Cretaceous coverage, or in the marbles of the (1b) case being away from the fault zone.

The fact that these problems concern only the marbles of the

fault zone, proves that these fractures, as well as the reason that caused the shear-fracturing zone, must be asked in the fault action.

We remind that the K. Loutraki fault is a dextral strike-slip fault. P. VIALON-M. RUHLAND - J. GROLIER (1976) give the Figure 3a for the consequent fractures of the 2nd, 3rd and 4th orders that accosiate a dextral strike-slip fault with direction N-S. In this figure are

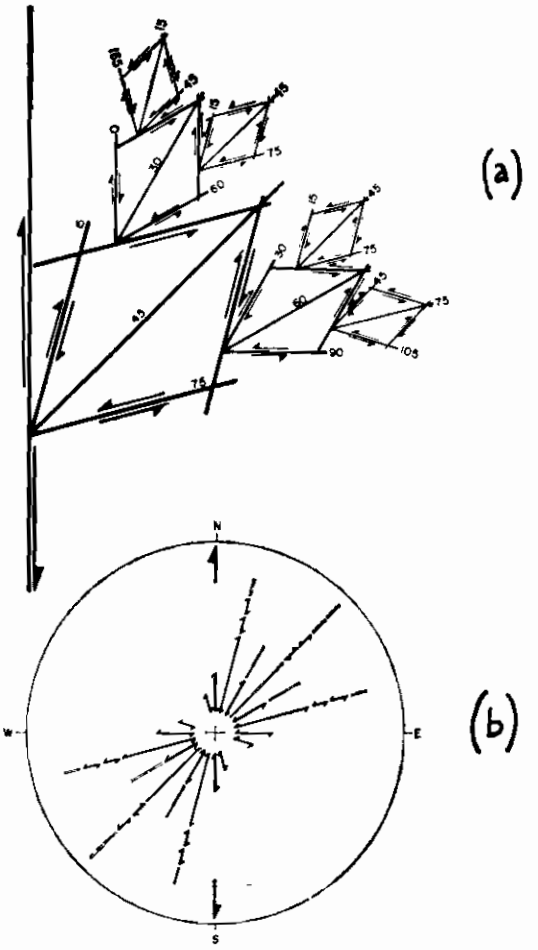

Fig. 3. Distribution of the shear-fractures of the consequent orders, which accompany a dextral strike-slip fault with direction N-S. a) The angular relations of the shear-fractures, b) Representation in rose of the disposition to the right of the shear-fractures distribution in relation to the initial N-S fault. Arrows long, medium, short: joints of 2nd, 3rd and 4th orders. (After P. Vialon - M. Ruhland - J. Grolier 1976).

also recorded the angular relations of the accosiating shear-fractures with the initial fault. The angular relations are also illustrated in the correlative rose (Fig. 3b) where we can see the disposition to the right of the distribution of the fractures and their frequency as well.

In the last figure the consequent 2nd order fractures and generaly the greater frequencies form with the initial fault angles corresponding to 15°, 45° and 75°. If we accept, for the area of Orma, the K.Loutraki fault with direction 70° as the initial fracture, then the equavalent consequent fractures must have directions 85°, 115° and 145°.

Choosing among the 200 greatest microfaults-joints of the marbles of the K. Loutraki fault zone (size greater than 8 m), which we considered as the 2nd order shear-fractures, we made the indicative rose of Figure 4, where only the greatest values, per 5°, are expressed. From that we extract that the main fractures have directions 0°, 5°, 10°, 85°, 115°, 125°, 135° and 145°. If we consider that the 0°, 5°, 10° and the 125°, 135° correspond with other tectonic phases, that is

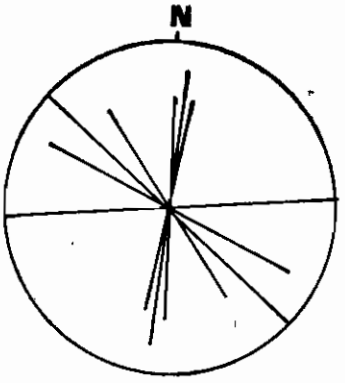

Fig. 4. Maximum values of 2nd order microfaults in the shear-fracturing zone along the strike-slip fault.

the former with the Lower Cretaceous phase and the latter with the Priabonian phase, then the rest of the shear-fractures (directions 85°, 115° and 145°) have the expected directions of the consequent fractures of the initial strike-slip fault.

Therefore, the set of joints with 85° direction and the large dispersion (100°-150°) found in the total marble joints of the case (1a) are mainly due to the consequent shear-fractures of the strike-slip fault. The subsequent Priabonian tectonic phase, which caused fractures of

the rocks with directions 125°-130°, has also contributed to the formation of the wide limits of the NW-SE set. For these reasons in the marbles roses are observed partly independent sets, sometimes with direction 110°-115°, sometimes with 120°-130° and some other times with 145°-150°.

The set 85° appears sensibly weak in the rose H of the marbles, representing measurements that took place in a relatively remote situation from the fault - at the limite of the shear-fracturing zone. It shows that the effect of the fault on the remote marbles decreases almost disappearing in the roses O and P.

In the roses N and O of the case (1b) a set of joints with 155° direction is independent. In the rose T of the crystalline basement we observe that the limit of the NW-SE set is expanded up to 160°. Even in the marbles of the case (1a) are observed declinations bejond 145° some times reaching the 155°.

These observations possibly indicate fractures of the pre-Upper Jurassic rocks parallelaly to the axis of the Upper Jurassic 1est folding which caused, according to VERGELY (1976), folds with axis 155° But the whole density at the NW-SE direction is too big to determine this fracture.

CONCLUSIONS

After analysing the joints of the Orma-K.Loutraki area we reached the following conclusions about the fracturing of the North Pelagonian zone: - During the U. Jurassic, before the Tithonian, appeared the first alpin folding with fold axis 155°. At this phase the dextral strike-slip fault was formed with direction 70°, that is transversely.

The fault caused consequent - accosiating fractures at a zone of 1 km width, with main directions 85°, 115° and 145°.

Probably during the same phase took place certain fractures on the crystalline basement and the marbles, paralellaly to the fold axis, that is with 155° direction.

— At the Lower Cretaceous, before Aptian, took place the 2nd folding with axis 0°-30, which has rather appeared as a strong fracturing tectonic phase with joints of 0°-10° direction on the marbles and the crysralline basement.

The joints of 0°-10° direction and the accosiating fractures of the K. Loutraki fault with directions 85°, 115° and 145°, as well as a possible reactivity of the fault during this period were, in our opinion, the

mainly creative reasons of the fracturing on the Pelagonian marbles — Finaly at the Priabonian, during the final folding, took place fractures with directions 130° and 45°-60° completing the tectonic fracturing of all the Pelagonian rocks.

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ΠΕΡΙΛΗΨΗ

ΠΑΡΑΤΗΡΗΣΕΙΣ ΣΤΗ ΡΗΞΙΓΕΝΗ ΤΕΚΤΟΝΙΚΗ ΤΩΝ ΜΑΡΜΑΡΩΝ ΤΗΣ ΒΟΡΕΙΑΣ ΠΕΛΑΓΟΝΙΚΗΣ ΖΩΝΗΣ

Ὑπὸ
ΔΗΜΟΣΘΕΝΗ Μ. ΜΟΥΝΤΡΑΚΗ
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Στὰ μάρμαρα καὶ τοὺς δολομίτες Τριαδικοῦ - Ἰουρασικοῦ τῆς Βόρειας Πελαγονικῆς, στὴ περιοχὴ Ὅρμας - Κάτω Λουτράκι τοῦ Νομοῦ Πέλλης, παρατηρεῖται μιὰ ζώνη τεκτονικῆς καταπονήσεως, πλάτους 1 χλμ. περίπου, κατὰ μῆκος ἑνὸς μεγάλου ρήγματος (ρῆγμα Κ. Λουτρακίου).

Ἡ τεκτονικὴ καταπόνηση ἐκφράζεται μὲ μυλωνιτίωση καὶ ἔντονη κατάκλαση τῶν μαρμάρων δολομιτῶν, φαινόμενα ποὺ δὲν παρατηροῦνται στοὺς ἀνωκρητιδικοὺς ἀσβεστόλιθους τῆς Πελαγονικῆς οἱ ὁποῖοι βρίσκονται ἐπικλυσιγενῶς τοποθετημένοι πάνω στὰ μάρμαρα.

Τὸ ρῆγμα Κ. Λουτρακίου ἔχει διεύθυνση 70°, ἀποτελεῖ ἕνα ἐγκάρσιο, δεξιόστροφο ρῆγμα ὁριζοντίου μετατοπίσεως καὶ ἡ δημιουργία του ἔλαβε χώρα στὴν ἀνωϊουρασικὴ φάση πτυχώσεων ποὺ προκάλεσε πτυχὲς μὲ ἄξονες διευθύνσεως 155°.

Μὲ τὴ στατιστικὴ ἐπεξεργασία μετρήσεων τῶν διευθύσεων διακλάσεως - μικρορηγμάτων στὴ ζώνη τοῦ ρήγματος καὶ γενικὰ στὰ μάρμαρα - δολομίτες Τριαδικοῦ - Ἰουρασικοῦ, καθὼς ἐπίσης στὸ παλαιοζωικὸ κρυσταλλοσχιστῶδες ὑπόβαθρο καὶ τὸ ἀνωκρητιδικὸ κάλυμμα τῆς Πελαγονικῆς. ἐπισημάνθηκαν οἱ ὁμοιότητες καὶ διαφορὲς τῶν ρήξεων στοὺς διάφορους σχηματισμοὺς καὶ διαπιστώθηκε ὅτι ἡ πυκνὴ κατάκλαση τῶν μαρμάρων - δολομιτῶν στὴ ζώνη τοῦ ρήγματος προκλήθηκε βασικὰ ἀπὸ ρήξεις διευθύνσεων N-B ἕως ΒΒΑ-ΝΝΔ (0°-10°), ΑΒΑ-ΔΝΔ (85°) καὶ ΒΔ-ΝΑ (115°, 130°, καὶ 145°)

Μὲ λεπτομερέστερη ἀνάλυση καθορίζεται ὅτι ἡ πρώτη διεύθυνση ἀντιστοιχεῖ σὲ ρήξεις ποὺ ἔγιναν στὴ κατωκρητιδικὴ (πρὶν τὸ Ἄπτιο) φάση πτυχώσεων. Οἱ διευθύνσεις 85°, 115° καὶ 145° ἀντιστοιχοῦν στὶς συνοδὲς - ἐπακόλουθες ρήξεις τῆς ὁριζοντίου μετατοπίσεως τοῦ ρήγματος. καὶ τέλος ἡ διεύθυνση 130° ἀντιπροσωπεύει ρήξεις τῆς τελικῆς τεκτονικῆς φάσεως τοῦ Πριαμπονίου.