

Geological Structures of the Kinta Valley Revisited Using Drainage Anomalies

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Abstract More than 50 % of the surface of Kinta Valley is covered by alluvium overlying Paleozoic sequences and Late Triassic granitic intrusions. The alluvium of the valley is thin (mostly less than 30 m thick). Limestone and shale are the dominant lithologies cropping out in the valley, and they have been severely deformed. Unfortunately, these rocks are restricted to small areas of the valley and they are highly weathered, thus making the correlations between outcrops and structural interpretation commonly speculative. In this paper, we make use of drainage pattern anomalies of rivers, streams, and dry thalwegs that commonly reflect subsurface structures or variation of thickness of sediments and may help regional interpretation. Two main anomaly sets have been identified; NE–SW and N–S. These anomalies might reflect slight or large normal faults, and they formed sigmoid-shaped structure after interpolation. Three hypotheses are proposed to illustrate the extensional process in terms of reactivation of faults, transtension, and shear partitioning. Shear partitioning is most likely to occur by distributing the oblique extensional stress into normal faults and strike-slip faults. The valley is shallower and narrower to the north, suggesting more intense shortening than in the southern part. Both shortening by thrust faults and subsequent extension may be rooted in the lower ductile crust beneath the large granitic plutons.

Keywords Kinta Valley · Drainage anomalies · Deformation · Cross section

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1 Introduction

The Kinta Valley is bounded by mountain ranges to the east and west and widens toward the south (Fig. 1). Rivers and streams which originated from the highland converge into the valley (lowland) by flowing following the regional slope forming a dense drainage system which carries the weathered materials of the mountain basement rocks. This drainage system is partially influenced by structures of the bedrocks such as fractures and folds. Several cores and wells drilled in the valley for ore exploration provide information concerning the thickness of the shallow sedimentary layers, which are generally less than 30 m (70 ft) thick [1]. As a result, the thin alluvium is likely to reflect the bedrock morphostructures caused by either differential compaction of sedimentary layers at the footwall and hanging walls of faults or to their reactivation.

In the past, deformation in Kinta Valley has been studied using multi-scale analysis that mainly focused on the dominant outcrops, limestone, and granite, whereas in fact, most of the valley is covered by alluvium. Thus, drainage anomalies analysis may help to extract geological information from the bedrock underneath the thin alluvium where data were previously lacking, resulting in revised interpretations. Basing on surface geological data, satellite imagery, and drainage anomalies, we present a map of the hidden structures of the Kinta Valley and two E–W cross sections from the Kledang Range to main range in order to better illustrate the structural setting.

2 Geological Setting

Various lithologies have been identified in the Kinta Valley. Some authors [1] have grouped them into a few geological successions, which are calcareous and arenaceous series, granite and alluvium. In terms of structural evolution, an early extension has been identified, followed by compression and a late extension [2]. The early extension is represented by small brittle conjugate fractures in the Paleozoic platform, which formed when the carbonate sediments deposited and started hardening by diagenesis during basin infilling, and fractured due to overburden. It was followed by a regional compressional regime, which led to the formation of conjugate strike-slip faults and a series of thrusts within the carbonate strata. It seems that the shortening propagated toward the east and increased approaching the contact with the granite of the main range. It is not clear if compression also affected the granite [3]. However, not far from the formerly hot granite contact, the limestone deformed in a ductile manner, as illustrated by localized flow structures and ductile pure shear. The ductile structures indicate both reverse and normal movement, suggesting a late gravitational collapse of the limestone parallel to the granite contact. The process would be similar to “roof-pendant” formation, but with high temperature (HT) conditions, and suggests the concomitance of the late stage of

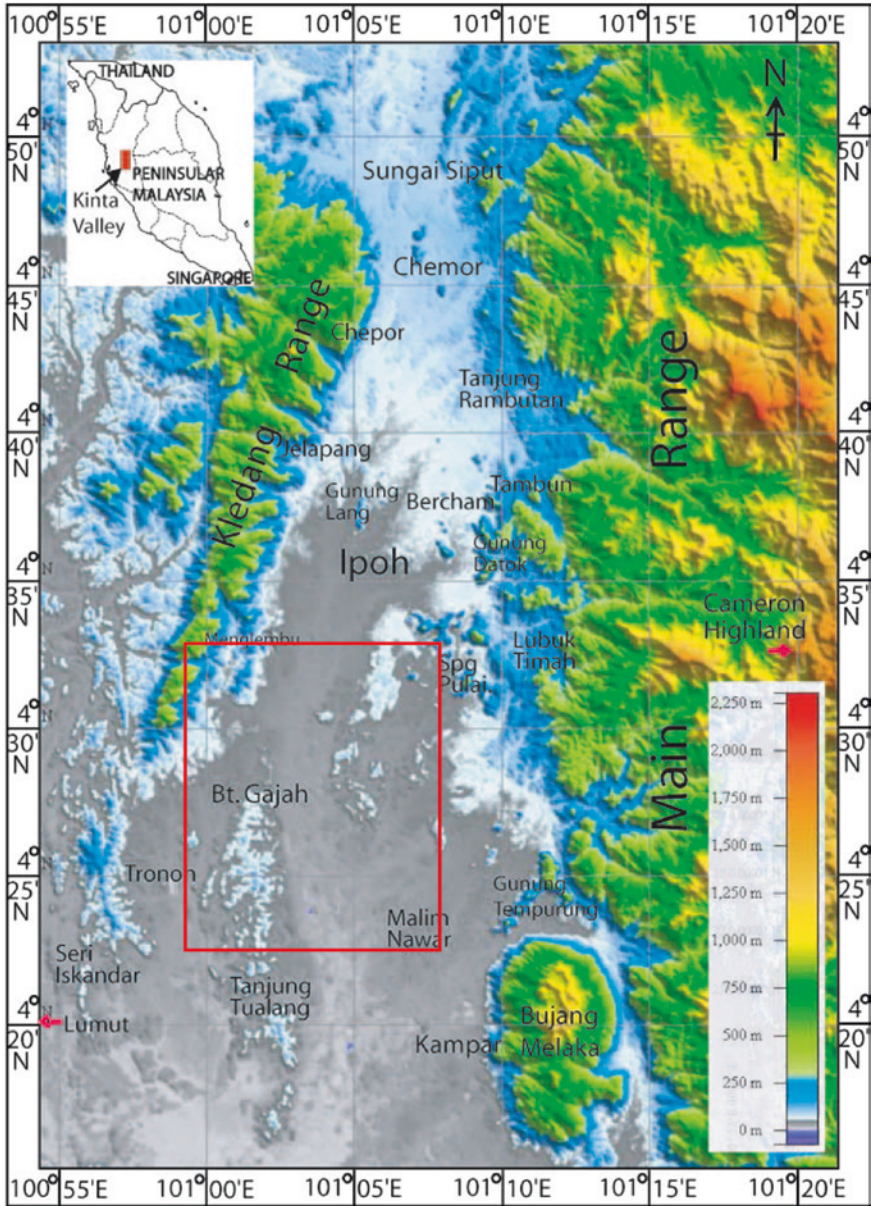


Fig. 1 Morphology and localities of Kinta Valley. The area between granitic intrusions (green and yellow) is mainly composed of alluvium (white and gray). The detailed drainage anomalies of Fig. 2 are shown in the red frame. Note the narrowing of the valley toward the North

granitic intrusion and the shortening. This region became extensional again as illustrated by large normal faults visible on the digital elevation model (DEM) [4] and satellite image. We correlate the late extensional event with the Tertiary horsts and grabens formation of the Strait of Malacca [5], the Mergui basins of the Sumatra, and other onshore Tertiary basins of Peninsular Malaysia, based on their similar orientation and structure.

3 Methodology

Rivers tend to flow naturally in the shortest path to the shoreline following the regional slope [6]. It is assumed that if it behaves in different way, it forms drainage anomalies which result from anthropogenic activities or local geological structures, topographic anomalies, or other external factors [7].

The drainage network of the Kinta Valley has been digitized and overlain on the DEM. The anomalies have been selected based on criteria [7] such as:

- Local modifications of the drainage pattern: The drainage locally appears in a pattern that differs from the dominant one. We identify, for example, radial drainage patterns including centrifugal and centripetal [8].
- Wide angle of river's convergence (the normal convergence is usually 60°), or divergence of the streams triggered by a subsurface topographic high.
- Stream directions not following the regional slope or marking a bayonet shape.

Anomalies are analyzed and interpreted in terms of potential geological structures such as bedding traces, faults, sagging zones, or underlying basement highs such as karst relicts or plutonic bodies. Based on structures inferred from drainage anomalies, and previous surficial geological information, a geological structural map was constructed, from which geological cross sections were constructed. The interpretation provides support for a discussion of the geological setting of the valley in terms of geodynamics and tectonics.

4 Results and Discussions

4.1 Drainage Anomalies

Analysis of drainage anomalies focused on the middle part of the valley (alluvium) where outcrops and therefore geological information were lacking or poor (Fig. 2). Two major sets of anomalies have been identified: NE–SW and N–S.

The NE–SW anomalies have a specific orientation, which may have some local deviations. These anomalies have been observed in the northern (e.g., Chemor) and southern ends (e.g., Batu Gajah–Gopeng) of Kinta Valley. They are commonly a few kilometers long and regularly spaced.

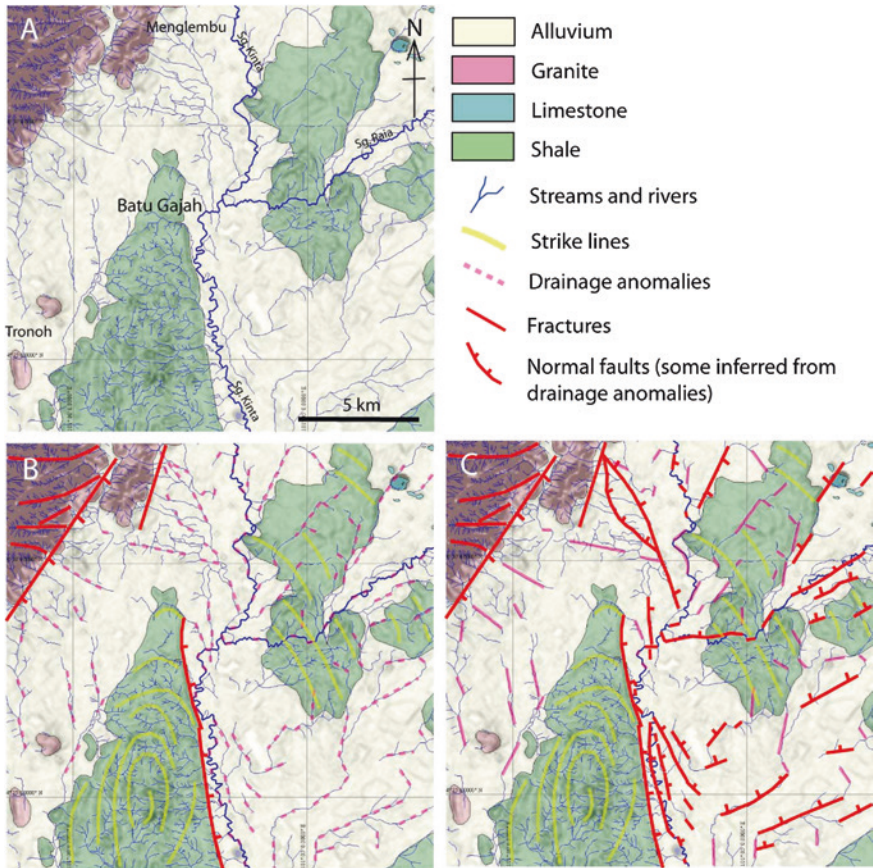


Fig. 2 a–c showing the steps followed in analysis and interpretation of drainage anomalies. **a** Detail map showing the drainage system and lithologies in the vicinity of Batu Gajah. **b** Drainage anomalies have been traced, together with fractures, normal faults, and strike lines of the beddings. **c** Some of the prominent the drainage anomalies have been correlated and interpreted as normal faults based on their curvilinear shape and their location at the edge of uplifted areas

The NE–SW anomalies are found in alluvium of the northern end of the valley, which includes north of Ipoh city, Tanjung Rambutan, and Chemor. They are totally absent in the valley flanks or granitic mountain ranges (Fig. 3). Parts of the major rivers such as Sg. Pari and Sg. Kinta have been included as large drainage anomalies. The average lengths of the anomalies (~5 km) suggest they are large faults. These faults are likely to result from a late deformation, because they crosscut other fractures. The NE–SW anomalies are also found in the southern part of the valley (Gopeng—Gunung Tempurung area next to the mountain range) (Fig. 3). Moving away from mountain range toward the Malim Nawar—Tanjung Tualang area in the west, the orientations of the anomalies are slightly deviated to ENE–WSW. Because of their curvilinear shape, these anomalies can be extended

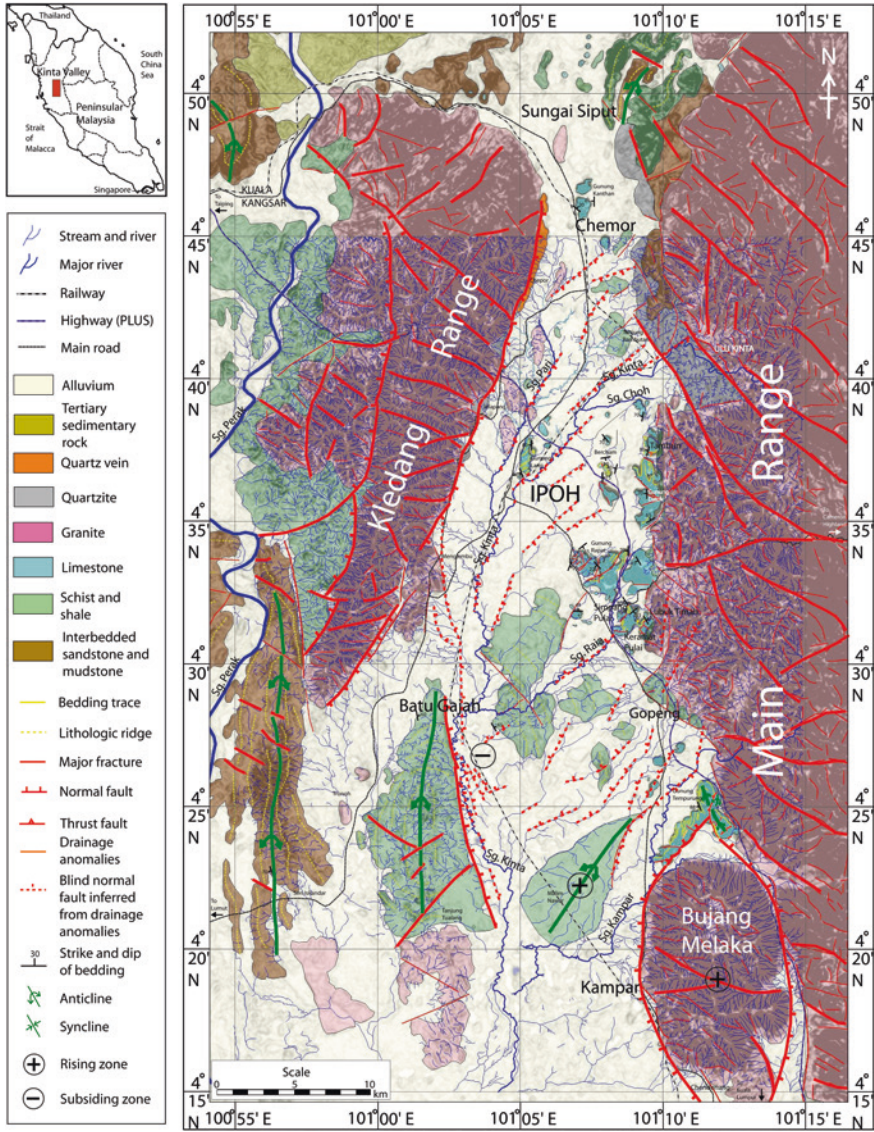


Fig. 3 Geological and structural map of the Kinta Valley, including the subsurface information deduced from the drainage anomalies

and connected to the N-S striking fractures to the granitic mountain range next to Gopeng town.

N-S anomalies are found near Sg. Kinta next to Batu Gajah and the southeast part of the Menglembu (Fig. 3). They are locally oriented NNW-SSE near the Tanjung Tualang area. They are closely spaced and localized. A normal fault near

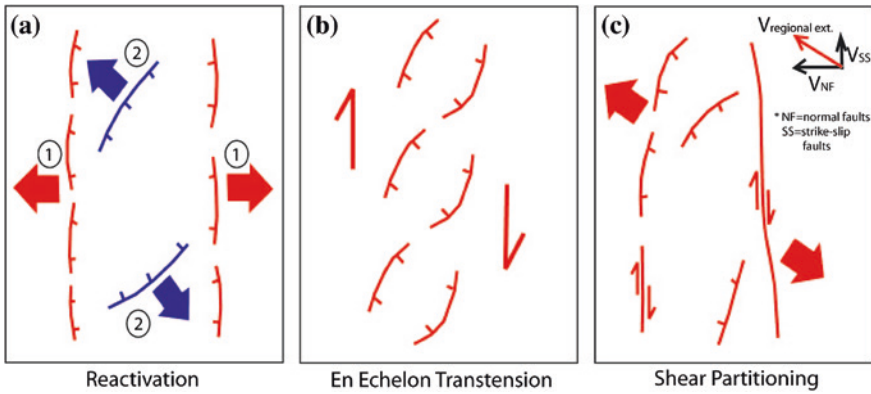


Fig. 4 Models illustrating the extension events that initiated the numerous normal faults in Kinta Valley. *Board arrow sets* indicate the extensional directions

Sg. Kinta, interpreted on DEM based on the change of the surficial texture, has an azimuth similar to this anomaly set.

A subsiding zone has been discovered at the intersection of the Sg. Kinta and Sg. Raia near Batu Gajah and labeled with a “-” symbol. The drainage disappears here and may connect to a groundwater system. These anomalies are likely to correspond to a late extensional event. Several additional structures have been observed in the valley, and these may be related to the late extension. They are namely, spoon-shaped normal faults (e.g., eastern part of the Batu Gajah), low-angle normal faults along granite (e.g., Simpang Pulai), and strike-slip faults (e.g., Lubuk Timah, Simpang Pulai). The geometry of the system encompassing these faults, close to a large pull-apart, suggests a component of strike-slip, which is not easy to see in the field. We propose three hypotheses to describe their occurrences (Fig. 4): (i) normal faults reactivated as strike-slip faults; (ii) a transtensional event consisting of faults that have both dip-slip and strike-slip components; or (iii) shear partitioning which distributed the oblique extensional stress into normal faults and strike-slip faults. Among these hypotheses, we favor shear partitioning as the initial extensional event because of the common existence of pure strike-slip and pure dip-slip faults in the valley.

4.2 Kinta Valley Cross Sections

The previous mapping using satellite imagery, DEM, and field observation has revealed that Kinta Valley is composed of few major lithologies (i.e., interbedded sandstone and mudstone, shale, limestone, and granite) with different geological structures. In order to illustrate the regional deformation of Kinta Valley, two large-scale E–W cross sections across valleys have been constructed (Fig. 5). As

mentioned above, Kinta Valley underwent an early extension in the Paleozoic platform, a syn-intrusive compression (Early Jurassic?) and late Tertiary extension. The early extension occurred at outcrop scale and is not represented on the sections. Thus, the structures observed in the valley are mainly the compression and late extension.

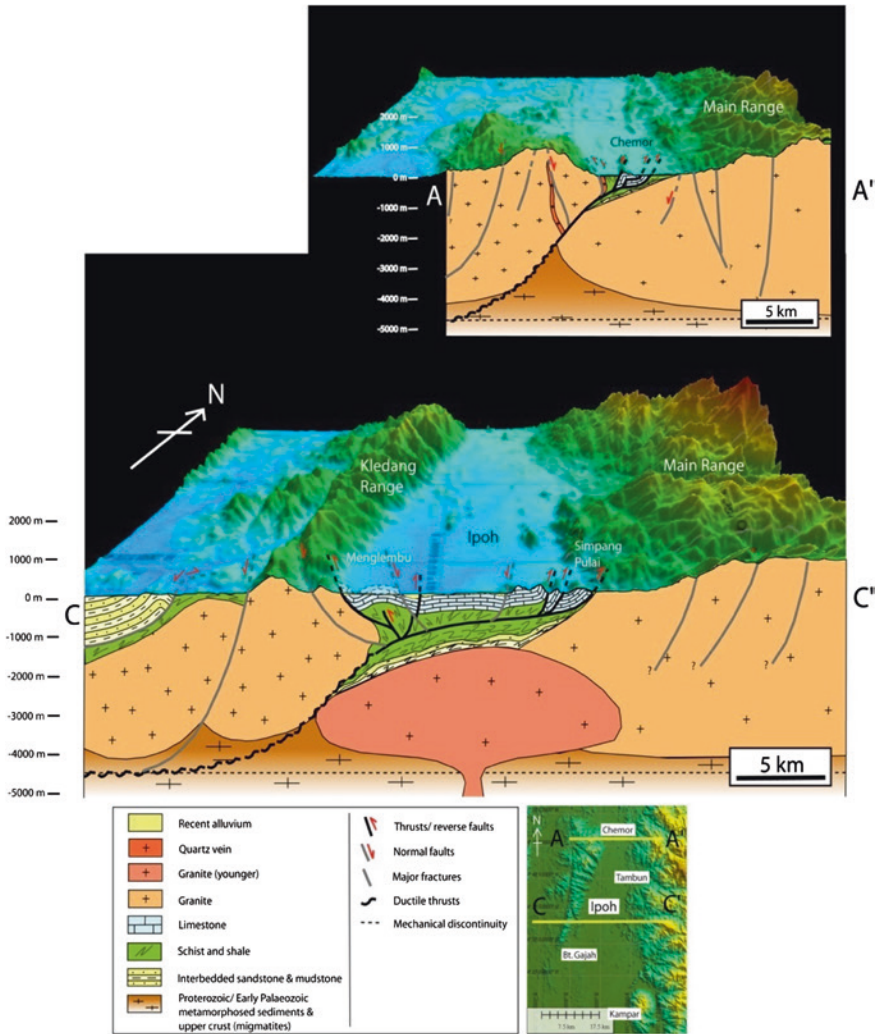


Fig. 5 Two E–W geological cross sections (A–A' and C–C') combined with DEM across Kinta Valley from the Kledang Range to the main range [9]. The sections illustrate that shortening affected the deep structures (including the basement and the granites) via deeply rooted thrusts propagating toward the surface into the thick black shale and the stacking of Paleozoic limestone. *Note* the increase of shortening from the south to the north of Kinta Valley

The compressional event occurred together with the granitic intrusion during Late Triassic to Early Jurassic time. All the preexisting rocks (interbedded sandstone and mudstone, schist and shale, limestone, and granite) were affected. The limestone close to the granite–limestone contact was shortened by folding. Thrust faults and tight folds are the main structure in this area, which contribute to the folding and tilting of the strata (Fig. 5). The important shortening of the limestone unit implies an effective decollement within the underlying lithologies, which are represented by over-thickened black clay. The deformation in the clay is severe at the scale of the outcrop but also visible for the first time on the map, in the form of a broad anticline. We propose that this geometry results from the shortening between the large granitic bodies of the Kledang Range and the main range, which in turn suggests that the thrust may be deep-seated and connected to the mechanical discontinuity at a few kilometers depth. The crustal thrust faults would ramp up to the shallow level (black shale) and then serve as a decollement for the Paleozoic limestone.

The granitic areas in the valley flanks are intensely fractured. As the granitic intrusions were cooling, they recorded the deformation as brittle fractures, which may have recorded the E–W compression as conjugate fractures. An extensional regime followed the compression, and this is evidenced by the propagation of normal faults reactivating existing discontinuities, e.g., fractures, thrust faults, or granite–limestone contacts.

5 Conclusions

Alluvium covers most of Kinta Valley and obliterates the main structures. They are thin (commonly less than 30 m thick) and accommodate a dense drainage system. Two major drainage anomaly sets, NE–SW and N–S, have been identified. Blind normal faults have been inferred from these anomalies and can be interpolated as large curvilinear structures. Three hypotheses have been proposed to illustrate the extensional event: (1) normal faults reactivated as strike-slip faults, (2) en echelon normal faults, and (3) shear partitioning dividing the extensional forces into pure strike-slip faults and pure normal faults, respectively. Based on field observations, shear partitioning is the most likely explanation for the occurrence of numerous blind faults marked by drainage anomalies. Two cross sections have been constructed based on the information extracted from field, satellite imagery, DEM, and drainage anomalies. The sections illustrate that the rock sequences of the valley are mainly affected by thrust faults, which accommodated the shortening and transferred the deformation from the deep crustal layers to the Paleozoic platform. The subsequent late extension led to formation of large normal faults, which may have reactivated the earlier structures at the contact between sediments and granite.

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