PLIOCENE–QUATERNARY LANDSCAPE EVOLUTION AND DEFORMATION IN THE EASTERN VÉRTES HILLS, (HUNGARY): THE HERITAGE AND REACTIVATION OF MIOCENE FAULT PATTERN.

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Abstract: The study area is characterised by N to NE trending half–grabens, formed during the late rifting phase (14–11 Ma) of the Pannonian basin. Fault location partly changed from Sarmatian to Pliocene. The youngest Pliocene sediments were also deformed, partly in Quaternary. Landscape evolution was determined by the fault pattern, via strongly contrasting erodibility of hard footwall and soft hangingwall lithology. An old erosional surface was probably upwarping, resulting in anomalous drainage.

Key words: Pannonian basin, faulting, landscape evolution, Quaternary, Pliocene, denudation

The study area is situated in the central part of the Pannonian back–arc basin. Recent structural analysis (Fodor et al. 1999) revealed the following structural evolution: two rifting phases, (an older, 18–14 Ma and a younger, 14–11Ma phase), a generally weak post–rift phase (late Miocene), and the "neotectonic phase" which corresponds to Pliocene–Quaternary inversion of the Pannonian basin.

The particularity of the study area is the pronounced late rift and post–rift faulting. Although the direction of tension did not changed significantly from late syn–rift to post–rift phase, fault locations jumped. Due to the presence of a latest Miocene(?)–Pliocene terrestrial sequence, faulting can be followed up to the late(?) Pliocene–Quaternary. All these structures considerably determined the landscape evolution. In addition, geomorphological evidences suggest that some of the syn– and post–rift faults could be direct antecedents of Quaternary structures.

Geological Settings

Stratigraphy of the study area comprises Triassic dolomite, Eocene bauxite, fanglomerate, siltstone, limestone and volcanites, Oligocene bauxite and clastics, middle Miocene marl, limestone, gravel, clay, evaporite (Jámbor 1969), upper Miocene "Pannonian" fine clastics (Jámbor 1980). Pliocene terrestrial clay, caliche, sand (Tóth 1971) may reach 150 m thickness and represent the new Vértesacsa Member of the Nagyalföld Formation.

The study area comprises two contrasting morphological parts; the eastern Vértes Hills and its southeastern foreland. Denudation during Cretaceous–Paleocene subtropical climate created an etchplain (Kaiser 1997). This landform was punctuated by bauxite–filled karstic depressions during the Eocene. This surface was temporally covered by sediments but exhumed and slightly lowered during early Oligocene, middle Miocene and Plio–Quaternary erosonal processes. It still dominates the landscape of the Vértes forming flat hilltops at 350–450 m.

N to NE trending boundary fault system separates the “Vértes plateau” from the eastern area made of “Pannonian” (late Miocene) sediments. This foreland is marked by subparallel, southeast trending valleys entrenching in smoothly lowering surface. One exeption occures near Vértesacsa, Nyárjas Hill where some NW–flowing creeks occur together with gently northwestward dipping ridge outstanding from the general landscape.

Tectonic and morphological evolution

Late synrift fault pattern and related lithofacies

The late Middle Miocene (Sarmatian, 13–11 Ma) outcrops consist mainly of cross–bedded oolitic and coarse skeletal limestones (tMs on Fig. 1) deposited on a narrow shelf/ramp environment (Jámbor 1969, Palotás 1994). Landward, limestones change to fine grained lagoonal deposits, locally with gypsiferous intercalations (bMs). Channelized gravels and variagated clays (gMs) were deposited in fluvial to fan–delta environment near the Vértes Hills. Basinward, the limestone is interfingering with marls, calcareous marls and claystones (kMs, Fig.1).

Sarmatian faulting resulted in half grabens, bounded by faults of N–S to ENE–WSW orientation. This deformation was marked by E–W to ESE–WNW tension, projected from nearby outcrops (Bergerat et al. 1983; Palotás 1994). Facies distribution clearly follows fault pattern (Fig.2a). Limestones occurre along major, N–S trending faults and also the ENE trending Felcsút ridge (Fig.1). The abrupt change from limestone to basinal marl also occurs near the fault zones, demonstrating that fault slip (subsidence) created accommodation space, which was not compensated by carbonate sediment production. Terrestrial sediments seem to fill a large channel entering the SE tilted half graben from the Vértes Hills.

Late Miocene to early Pliocene deformation and paleogeogrpahy

Stress field did not seem to change in the late Miocene–early Pliocene. Abruptly changing Pannonian thickness between boreholes suggest the continuation of synsedimentary activity along some faults (Fig.1). The major difference of fault pattern between Sarmatian and late Miocene–Pliocene is the activation of the easten boundary fault zone of the Vértes (Fig.1,2b). Sarmatian facies show gradual shallowing toward this fault zone, suggesting that it did not exist before Pannonian. On the contrary, “Pannonian” marginal lithofacies, talus breccias, abrasional gravels (dPa2), beach sand (zPa1, klPa2) and synsedimentary dykes are frequent along the fault zone. Thus, the eastern boundary fault represented the western boundary of the late Miocene depocenters.

Faulting was reactivated in the Pliocene, after the depostion of the Vértesacsa Member, while all formations are cut by map–scale and outcrop–scale faults. In addition to basin margin fault, the Felcsút ridge became active, downfaulting the terrestrial Vértesacsa Member to the SE (Fig.1, 2b).

Plio–Quaternary landscape evolution and possible deformation

Late Pliocene to Quaternary denudation and Quaternary sedimentation is partly controlled by the exisiting, herited fault pattern of the area. Fault controll is mainly made by the different erodibility of the rocks. Relatively soft "Pannonian" strata were almost completely removed from the western footwall of the eastern boundary faults and older etchplains were exposed again. Tertiary sediments were only kept in tectonic depressions (Fodor et al. in press).

The foreland was eroded by wind and slope wash, resulted in the formation of “old” (now eroded) pediment surface(s) on top of the sediments. Dolomite and quartz clasts derived from the Vértes plateau were transported SE, up to the Nyárjas Hill area.

Erosion of the “old pediment” was made by alternating wind erosion, slope wash and fluvial incision (Fig.2c, d). The lithology–selective process eroded completely the thin Vértesacsa member NW from the Felcsút ridge and fastly lowered the landscape through the easily erodable “Pannonian” strata. The eastern boundary faults became exposed and supplied local fans of dolomitic debris. Away from the exposed fault scarps, several levels of pediment surface developed and were covered by thin dolomite proluvium (Fig.2c–e). Higher P4 and P5 are small and ambiguous (Fig.2b–e), P2 and P3 are larger flat–topped areas while the lowermost P1 is situated in a broad valley.

Deflation/river incision resulted in gradual abandonment of earlier pediments, redeposition of earlier pediment debris in small channels and in colluvium, formation of deflation holes (blownouts), ventifacts on pediments, smoothing of steep valley slopes, etc. Gently dipping slopes experienced the accumulation of thick loess and sand dunes, while steep slopes were deformed by slides, while valley bottoms were still dominated by alluvial sedimentation (Fig.2d, e).

The Nyárjas Hill did not follow this landscape evolution after the erosion/incision of the “old” pediment surface (Fig.2b). Two factors contributed to its anomalous behaviour. The hill is consisted of the Vértesacsa Member downfaulted along the Felcsút ridge. These sediments became more resistant against erosion than the “Pannonian” strata on the NW and were gradually exhumed, now forming the relatively high Nyárjas hill.

On the other hand, dolomite clasts on the Nyárjas Hill could be transported from the Vértes only during the first denudation phase (Fig.2b). To reconstruct the transport surface, the observed pediment slope trend was projected from the top of the anomalous Nyárjas Hill northwestward (Csillag et al. 2001). The measured segment of P2 has a slope of 0º55' to 0º40' while P1 pediment terrase and Holocene alluvium are dipping 0º11'. The projected erosional surface is above the highest Triassic hilltop. This contradicts to a once continous erosional surface because it is expected to hit the eastern fault scarp, the source of dolomite clasts. This is only possible if the Nyárjas Hill was elevated with respect to the Vértes plateau and eastern fault scarp, after the first pediment formation (Csillag et al., 2001). The inferred Quaternary movement might have occurred along faults of the Felcsút ridge (Fig.2c,d). This reverse (strike–slip?) fault reactivation could be associated with upwarping of the hangingwall (Nyárjas Hill). This would tilt slightly the hill to NW and divert some creeks from SE to NW flow direction. Slopes became particulary sensitive for gravity mass movements (slides, soil creeps, mud flows) along all the resulted "anomalous" and stronly incising drainage. Weak seismicity indicates a possible tectonic activity up to present (Kiszely 2001).

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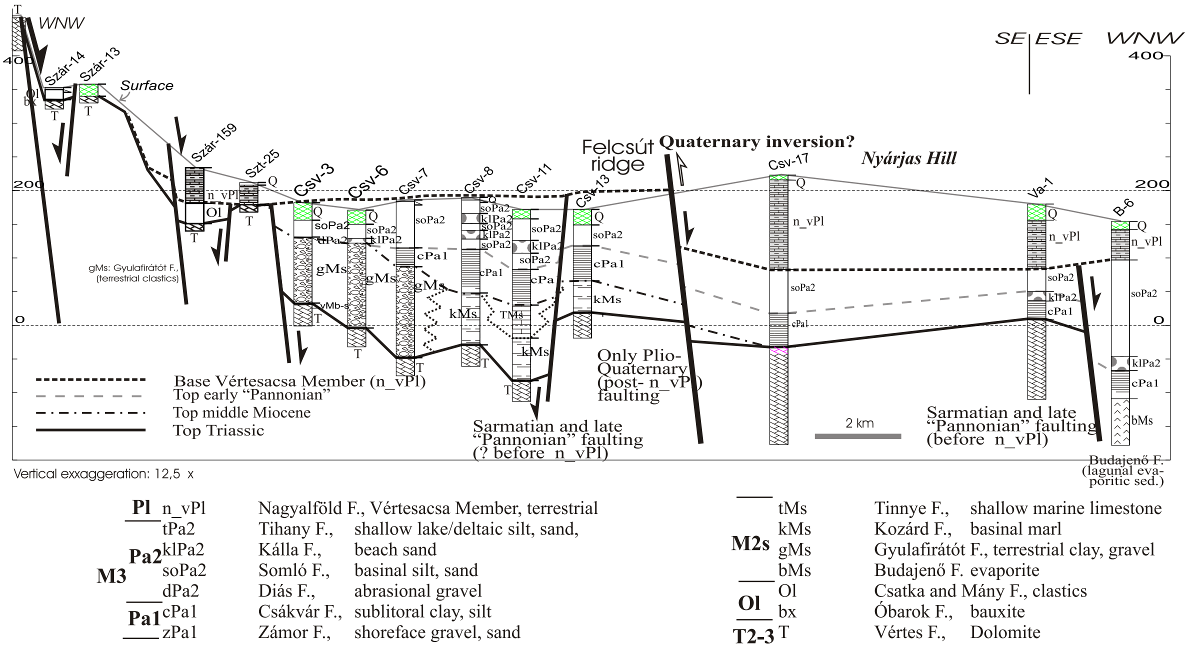
Fig. 1. Cross section in the study area, after Csillag et al. (2001).

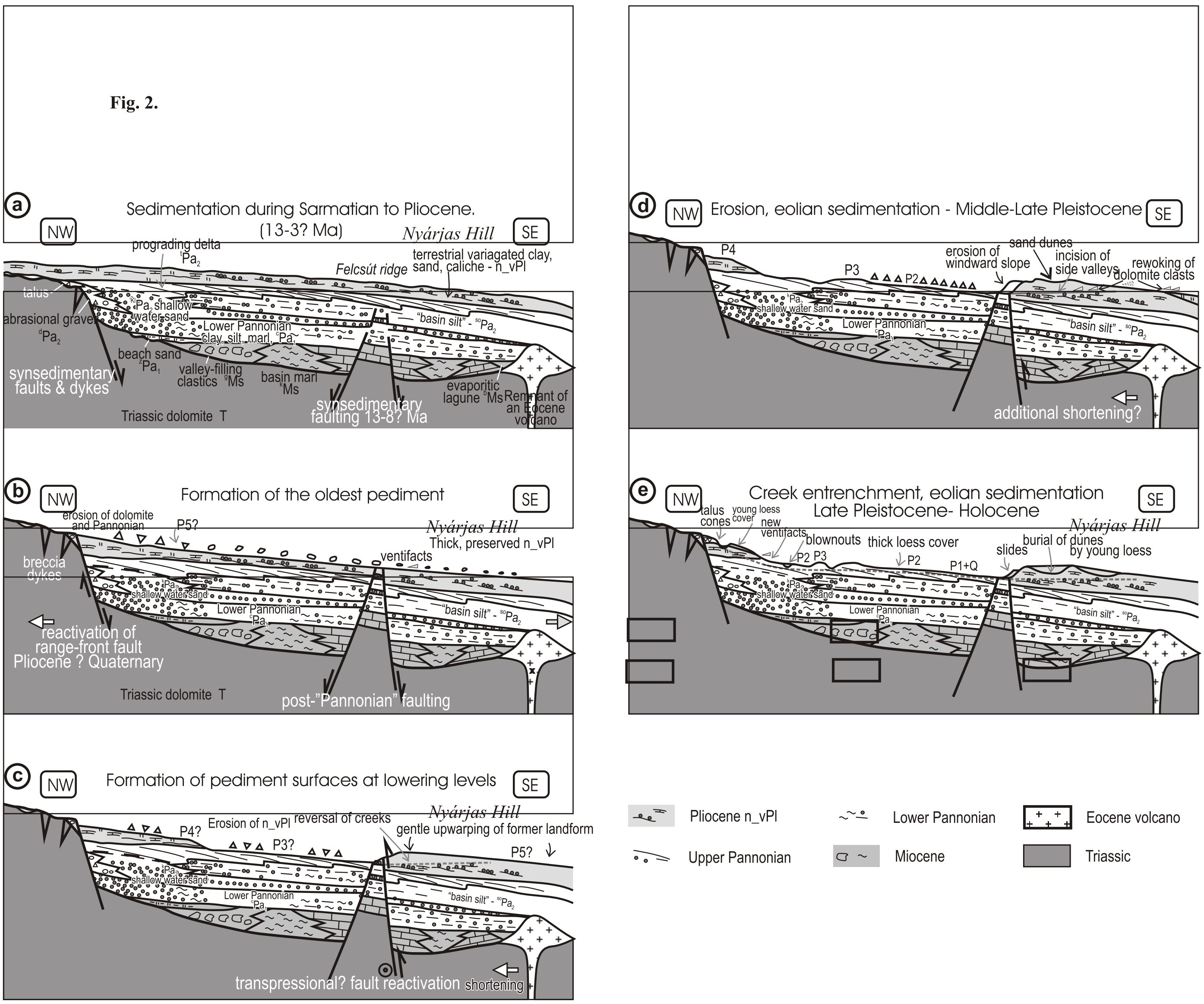
Fig. 2. Conceptual evolution model for the area. For legend see Fig. 1. After Csillag et al. (2001).

Fig. 1.



WNW
SE
ESE
WNW
400
200
0
Szár-14
Szár-13
Surface
Szár-159
Szt-25
Csv-3
Csv-6
Csv-7
Csv-8
Csv-11
Csv-13
Felcsút ridge
Quaternary inversion?
Nyárjas Hill
Csv-17
Va-1
B-6
gMs: Gyulafirátót F., (terrestrial clastics)
Only Plio-Quaternary (post- n_vPl) faulting
Sarmatian and late "Pannonian" faulting (? before n_vPl)
Sarmatian and late "Pannonian" faulting (before n_vPl)
2 km
Budajenő F. (lagunal evaporitic sed.)
Base Vértesacsa Member (n_vPl)
Top early "Pannonian"
Top middle Miocene
Top Triassic
Vertical exxaggeration: 12,5 x
Pl n_vPl Nagyalföld F., Vértesacsa Member, terrestrial
M3 Pa2 tPa2 Tihany F., shallow lake/deltaic silt, sand,
klPa2 Kálla F., beach sand
soPa2 Somló F., basinal silt, sand
dPa2 Diás F., abrasional gravel
Pa1 cPa1 Csákvár F., sublitoral clay, silt
zPa1 Zámor F., shoreface gravel, sand
M2s tMs Tinnye F., shallow marine limestone
kMs Kozárd F., basinal marl
gMs Gyulafirátót F., terrestrial clay, gravel
bMs Budajenő F. evaporite
Ol Ol Csatka and Mány F., clastics
bx Óbarok F., bauxite
T2-3 T Vértes F., Dolomite

Fig. 2.



a
Sedimentation during Sarmatian to Pliocene. (13-3? Ma)
NW
SE
Nyárjas Hill
prograding delta
terrestrial variagated clay, sand, caliche - n_vPl
Felcsút ridge
talus
abrasional gravel
shallow water sand
Lower Pannonian clay, silt, marl
"basin silt"
beach sand
valley-filling clastics
basin marl
synsedimentary faults & dykes
synsedimentary faulting 13-8? Ma
evaporitic lagune
Remnant of an Eocene volcano
Triassic dolomite T
b
Formation of the oldest pediment
erosion of dolomite and Pannonian
P5?
Thick, preserved n_vPl
ventifacts
breccia dykes
reactivation of range-front fault Pliocene ? Quaternary
post-"Pannonian" faulting
c
Formation of pediment surfaces at lowering levels
P4?
Erosion of n_vPl
P3?
reversal of creeks
gentle upwarping of former landform
transpressional? fault reactivation
shortening
d
Erosion, eolian sedimentation - Middle-Late Pleistocene
P4
P3
P2
erosion of windward slope
sand dunes
incision of side valleys
rewoking of dolomite clasts
additional shortening?
e
Creek entrenchment, eolian sedimentation Late Pleistocene- Holocene
talus cones
young loess cover
new ventifacts
blownouts
thick loess cover
P2
P3
P1+Q
slides
burial of dunes by young loess
Pliocene n_vPl
Upper Pannonian
Lower Pannonian
Miocene
Eocene volcano
Triassic