Geomorphological evidence for a changing tectonic regime, Pasinler Basin, Turkey.

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Abbreviated title: **Tectonic landforms in the Pasinler Basin.**

Geomorphological evidence for a changing tectonic regime, Pasinler Basin, Turkey.

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Abstract:

The Pasinler Basin, in the ‘East Anatolian Contractional Province’, features a suite of geomorphological zones, visible in the field, air photographs and Landsat and SRTM DEM imagery. These zones reflect past and current tectonically influenced processes. Relicts of the Erzurum-Kars plateau representing Mio-Pliocene volcanism, associated with transtensional tectonics, have been modified by two stages of drainage development: an earlier, shallow valley network, which was modified following uplift and tilting to form the present system characterised by deep narrow valleys that supply alluvial fan complexes. These fans discharge onto the present, aggradation-dominated basin floor. Initial normal faulting induced massive slope failures on the basin's northern margin. This extensional phase within the basin was reversed by the Late Pleistocene, with thrust faults modifying and producing landforms, and affecting sediments sequences, along both its northern and southern margins. The shift from a transtensional regime, and the associated volcanism to normal faulting in the Pliocene to Early Pleistocene, and then to the present regime of compression-induced thrusting appears to correspond with a regional tectonic shift resulting from the collision of the Eurasian and Arabian plates and the subsequent westwards movement of the Anatolian microplate.

Abstract: 190 words

Text: 4551 words

References: 752 words

Figure captions: 232 words

The effects of collision between the Arabian and Eurasian plates, and the associated escape of the Anatolian microplate to the west, dominate the landscape of eastern Turkey and surrounding areas. A series of well-known major faults (Dewey *et al.* 1986; Bozkurt 2001) reflect both thrusting and strike-slip displacement, though recent seismicity (Orgulu *et al.* 2003) suggests the latter is currently dominant. One consequence of this in eastern Anatolia is a series of fault-bounded basins representing localised extension induced by lateral shear and regional uplift (Dewey *et al.* 1986).

Extensive volcanism associated with these basins took place during the Neogene and has resulted in thick successions of igneous rocks, the upper surfaces of which are often planar, forming plateaux (Bayraktutan 1985; Keskin *et al.* 1998). Current volcanic activity is centred on crustal structures where ongoing movement is occurring (Adıyaman *et al.* 1998), most notably in pull-apart basins bounded by active faults (Karakhanian *et al*. 2004). Much of the area has not been directly affected by volcanism since the late Tertiary, and has experienced landscape evolution in response to other controls (principally tectonic activity and climatic change). Research in eastern and southern Turkey suggests the style of tectonism has varied through time, reflecting initial collision-related compression, then a more complex, spatially variable lithospheric response as the faults bordering the Anatolian microplate developed during the Pliocene (Jaffey & Robertson 2001; Over *et al.* 2004a). Much of the existing work on this response has focused on the major tectonic lineations of the Northern Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ) that meet near Karliova (e.g. Over *et al.* 2004b). In comparison, there has been limited consideration of the complexity and chronology of tectonic processes north and east of Karliova, in the ‘East Anatolian Contractional Province’ (EACP; Bozkurt 2001) despite the evident active faulting and uplift, and the historical record of damaging seismicity.

This study focuses upon a small area in the EACP, the Pasinler Basin [N39º58' E41º58'], approximately 40 km east of the city of Erzurum (Fig.1). The approach combines field survey and air photograph interpretation with remotely sensed data. Pasinler is particularly suitable because of the range of clearly expressed and contrasting landforms present within a limited area. . Moreover, this area is believed to be representative of the wider contractional province (Rust et al. 1999) and insights gained here may aid understanding of this relatively unstudied region, while the methodology may be generally applicable to studies within similar tectonic regimes worldwide. Although the basin is crossed by several faults, some areas appear not to have been directly affected by recent movements and thus have the potential to preserve features reflecting other palaeoenvironmental controls (*cf.* Rinaldo *et al.* 1995). The area is also seismically active, with a long historical and instrumental record of damaging earthquakes, for example in 1924 and 1983 (Eyidogan et al. 1999). Improved understanding of the geomorphic expression of this activity should contribute to future research on longer-term hazard assessment.

The Pasinler Basin

The Pasinler Basin originated in the Miocene through extension, associated with regional uplift of the East Anatolian Accretionary Complex and perhaps induced by slab breakoff (Keskin 2003), with Eocene volcanic and sedimentary rocks being overlain by Miocene and Pliocene igneous materials that accumulated to thicknesses of several hundred metres (Keskin *et al.* 1998). The last significant igneous activity in the immediate vicinity of the Pasinler Basin is represented by lavas and ignimbrites produced after about 7.8 Ma BP that underlie the Erzurum-Kars Plateau.   Younger volcanic rocks occur to the south and east (Keskin et al. 1998), suggesting a significant migration of the regional stress field since the Miocene (Koçyiğit et al. 2001). During the

Miocene and Pliocene, erosion of the Plateau sequence was associated with deposition of thick fluvial and lacustrine sequences (the Yastıktepe, Aras and Horasan Formations – Kurtman and Akkuş 1971; Rathur 1975; Bozkuş1993; Dayan 2005) and this denudation has continued through the Pleistocene and Holocene, with the basin floor occupied by extensive clastic sediments at least 80m thick (Bozkuş 1993).

Low magnitude seismicity (<M4) is frequent and the basin has been affected by a number of higher magnitude destructive events, most recently the Pasinler and Horasan earthquakes in AD1924 and AD1983 respectively (both Ms 6.8: Bayraktutan *et al.* 1986; Eyigodan *et al.* 1999). Seismicity is mainly associated with strike-slip movements along the NE-SW trending North East Anatolian Fault zone (Fig. 1) and related structures, though some appears linked to thrust faulting (Eyigodan *et al.* 1999).

The Pasinler Basin occurs near the regional drainage divide (Fig. 1). To the east, separated from the basin by a low col, are the headwaters of the Euphrates, which drains to the Persian Gulf, while catchments to the north drain into the Black Sea. The Basin itself is part of the headwaters of the River Aras, which drains east to the Caspian Sea.

The region occurs in the transition between true dry steppe to the east and more temperate climate zones to the west. The climate here is markedly seasonal, with continentality producing dry, hot summers and cold winters, often with heavy snowfall. This seasonality is reflected in surface hydrology, with river flows being highest in the spring and early summer while catchment soils are desiccated by late summer. Late-lying and permanent snow occurs at higher elevations.

In the past, a variety of climatic conditions have prevailed. During the Pliocene, conditions may have been broadly similar to that of the present interglacial, if perhaps a little warmer (*cf.* Zubakov & Borzenkova 1988). During much of the Pleistocene, the region was significantly colder. Possible glacial landforms and sediments occur north of the basin, and the Pleistocene glaciation of Mt Ararat, east of the basin, is well established (Altınli 1966; Birman 1968). There is little unambiguous evidence for glaciation within the basin itself, however.

Geomorphology

Identification of geomorphological zones and the nature of the drainage network (Figs 2 and 3) was accomplished through a combination of techniques. These included analysis of stereo aerial photographs, 1:25,000 topographic maps, Landsat ETM+ (image 171r032_7x20000905), a digital elevation model (DEM) derived from SRTM data with a spatial resolution of approximately 90m (accessed from GLCF 1997-2005) and field survey. The identified zones are considered in turn below.

I. Plateaux

The northern and southern parts of the basin feature high-altitude, quasi-planar surfaces and higher ground up to 3000 m above sea level. These are part of the extensive Erzurum-Kars Plateau, formed during Mio-Pliocene volcanism (Keskin *et al.* 1998). The northern and southern plateaux have contrasting geomorphology and can be considered separately.

The northern plateau includes two elements, differentiated by surface slope and drainage network characteristics. For most of its area, the eastern element of the plateau (Ia) is roughly planar, with typical gradients of 1.3-2.8 m km^{-1}. Underlying volcanic strata are near-horizontal, except near the southern edge of this plateau element, where they exhibit southerly dips of 20°-30°. Overlying the igneous strata across much of the plateau, to varying depths, is the Aras Formation (Keskin 1998). The surface is cut by two generations of valleys. The earliest is a network of shallow valleys, the largest of which are oriented approximately WNW-ESE (i.e. perpendicular to the main plateau slope). The trellis-like pattern of these valleys indicates a structural control, perhaps by minor folds or faults. There are no obvious lateral offsets, or sudden changes in elevation, suggesting that this network exploited inactive structures. These valleys probably represent the initial Pliocene drainage network.

The shallow valleys on the eastern element feed into deep linear gorges, such as near Büyukdere (Fig. 2). As individual lithostratigraphic units are spatially extensive and approximately horizontal beneath most of the plateau (Keskin et al. 1998), it is clear that these are structurally controlled, with a dominant SW-NE orientation, following the regional pattern of SW-NE strike-slip structures. Headward erosion has led to modification of some of the earlier valleys, creating valley forms with a higher, more rounded element, cut through by a deep, steep sided element. Some confluences are angled upstream, suggesting a reversal in flow direction due to either capture or tilting.

Where they leave the plateau the largest gorges shift orientation to the southeast. Koçyiğit *et al.* (2001) suggested that this indicates lateral offset along a WSW-ENE strike-slip fault (which they refer to as the 'Timur Fault'). Our analysis does not support the presence of this fault as adjacent, smaller gorges do not all show the same offset and so the change in direction is due to flow locally following smaller NE-SW faults.

The westernmost element (Ib) consists of a planar surface that dips to the southeast, with typical gradients of 2.7-5.5 m km^{-1}. Slope angles increase towards the escarpment that marks the plateau's southeastern limit. Compared to the eastern element there are relatively few channels and most of these are straight. Two gullies extending from the western wall of the Büyukdere gorge have eroded a short way into the western plateau.

The transition between the two northern plateau elements occurs in two zones of gradient change. The first is along the Büyukdere gorge, while the second occurs roughly parallel to this, a short distance to the west. This latter feature links up with fault-guided landforms to the southwest (see below) and reflects a zone of tectonically-induced steepening.

Both Ia and Ib exhibit a progressive increase in gradient towards their southern margins. This appears to be due to a monoclinal flexure (Keskin *et al.* 1998), with a gradual increase in surface gradient towards the south mirrored by increasing dips of igneous strata (Fig 4). Immediately north of Pasinler, across an east-west fault (possibly a back thrust) the surface elevation increases.

The <u>southern plateau</u> (Ic) is much more deeply incised than its northern counterpart. This partly reflects contrasts in lithology, with outcrops of carbonates and ophiolites, and perhaps also its greater distance from the nearest, most recently active volcanic centres.

The dominant W-E trending major valleys are associated with regional strike-slip faults that extend beyond the valley (Bozkurt 2001) The dominant SW-NE trend of tributary valleys may simply be an expression of slope, though there may also be a continuation of fractures associated with the Cobandede Fault Zone (Fig. 2).

II. Alluvial fans

Fans fed from steep, narrow valleys occur along much of the basin margin. Exposures west of Alvar and north east of Pasinler reveal a range of lithologies typical of high-energy fan sediments (Rachocki 1981; Collinson & Thompson 1989; Pope & Wilkinson 2006), and indicate deposition by flowing water and debris-rich mudflows. The fan at the mouth of the Büyukdere gorge, immediately west of Pasinler, is deeply incised. In contrast, other fans are not incised and many are crossed by multiple shallow channels and palaeochannels, suggesting avulsion, and recent, perhaps ongoing aggradation. Some of this variation, particularly in the proximal part of the fans, may reflect different stages in a cycle involving reworking of fresh landslide deposits, fan aggradation, followed by incision as the volume of landslide debris available for reworking diminished (Rust 2005).

Most of the fans are restricted to the basin margins. The exception is the Altınbaşak fan, which is fed by an ephemeral channel with a large catchment. This fan extends across the whole basin floor to town of Pasinler, probably overlying and interdigitating with, deposits delivered by streams from the western part of the basin.

III. Large mass movements

Centred on Porsuk, on the northern margin of the basin, fan deposits lap onto and in places are overridden by, landslide and debris avalanche depositional complexes. The largest of these originated in three main semi-circular scars, between 1 and 2 km across, north of Porsuk (L1-3 on Fig. 2). These scars extend between approximately 2300m and 2700 m above sea level (approximately 1100m above the valley floor). The forms of the scars seem fault-guided (Fig. 4). The back walls are aligned with SW-NE oriented lineations, while the steep, sub-planar sides of the scars above Büyükdere appear structurally controlled.

The surface morphology of the flow complex is chaotic. Immediately below the eastern collapse amphitheatres are large mounds, possibly representing intact blocks up to 250m long and 100m wide. The distal part of the flow complex includes mounds and rafted blocks, some rising more than 30m above the surrounding surfaces. Large boulders (mainly highly weathered, lichen-covered igneous rocks) are frequent across the complex (Fig. 5). Sudden stalling of the flow is indicated by the steep front of the flow complex's toe and an abrupt break in slope marking the edge of the basin floor (Fig. 3). A number of lateral scarps can be recognised, related either to faulting expressed on adjacent fan surfaces, or movement within the flow complex after initial emplacement.

A large mass movement complex occurs north east of Büyuk Tuy (L4), possibly with the same fault-determined failure plane as the Porsuk mass movements. The dimensions of the scar above this slide are similar to each individual scar above Porsuk. The entrance to the semi-circular scar is partially blocked by a large landslide block (cf. Rust 1993). Post-movement modification, by faulting and deposition, has modified the surface expression of the runout beyond this block so that it is less obvious than for the

Porsuk complex. Accumulations of angular boulders occur on higher ground at Yiğittası (Fig. 4), indicating a minimum runout length of 4 km.

No mass movements of this scale occur elsewhere in the basin, though smaller failures are common on steeper slopes along the southern margin.

IV. Tectonically modified features:

The basin is bounded by a series of major tectonic lineations, some of which displace recent alluvial deposits within the basin. The mean density of the lineations is approximately 11.3km/km^2 (Fig. 2). Around 82% of total lineation length occurs as straight, or near-straight features, associated with both strike-slip and normal components of movement. The remainder are curvilinear, associated with thrusting.

In addition to modifications affecting landforms discussed above, a number of other landforms reflect active tectonic processes. The largest of these is the high ground immediately north of Pasinler (zone IVa; Fig. 5). The steep southern margin of this feature is steep and cut by a series of gullies, and represents a landsliding hazard to the town. By contrast, the northern side of the feature slopes continuously back, towards the plateau and the whole structure appears to be a back-tilted thrust block. The linear margins of this feature are bounded by NNW-SSE strike-slip faults; the western margin fault appears dextral and the eastern sinistral, suggesting that they are tear faults accommodating the generally southward directed thrusting. This interpretation is consistent with the fact that they lose their identity northwards, away from the thrust front, on reaching the plateau and the series of through-going SW-NE strike-slip faults.

Back tilting has also affected the southern margin of the basin, notably south of

Alvar (Figs 2-4) where a series of 1-5km wide lobate thrust fronts occur. Once again, individual lobes have linear lateral margins picked out by ephemeral streams. Exposures on this margin of the basin reveal coarse, poorly consolidated fluvial sediments that have been deformed by thrusting (Fig. 6), and are consistent with the interpretation that these structures are active.

Extending east and west of Pasinler the alluvial fans exhibit distinct curvilinear breaks in slope with an overall WSW-ENE orientation while, near the valley floor, these rounded slope breaks are associated with wetter soil conditions and springs, producing a belt of vegetation conspicuous on aerial photographs. Together, these characteristics indicate local impounding of groundwater upslope from thrusts cutting the fanglomerates and producing linear deformation fronts. Such post-depositional fault activity and fan deformation is also indicated by wide variations in fan gradients, from 7.6 m km^{-1} for the Büyükdere fan north of Pasinler, to maximum gradients of only 1.7 m km^{-1} for some fan surfaces on the southern margin of the basin (Fig. 2).

At Yiğittası, faulting has cut, and possibly tilted a broad landslide runout surface, resulting in a small valley (Fig. 4). The stream associated with this valley has been diverted away from its confluence with the Çaykara channel so that it is now part of the Porsuk channel system, leaving a wind gap that appears to have been produced by post-depositional tilting. Tectonic activity may also have contributed to producing a suitable setting for the ancient tell of Sos Hüyük, located in Yiğittası (Sagona 2000) by generating a vantage point and providing a good water supply.

East of Altınbaşak a linear block (zone IVd), capped by fanglomerate deposits, and extending across the basin with a SW-NE axis, displays relative uplift, with its surface now up to 50m above the surrounding valley floor. The linear margins of this feature suggest fault control are involved (perhaps a thrust and back-thrust) but, since drainage channels following the maximum gradient of the valley floor are parallel to the feature, no distinctive changes to the drainage pattern are evident. Erosion by the Hasankale river has here exceeded the rate of tectonic uplift, leading to a shallow, 1 km wide, breach in the ridge, 4.5 km west of Köprüköy (Fig. 2). A similar constriction in the valley floor at Köprüköy itself, associated with another linear fault-bounded ridge, marks the eastern limit of the basin. The strike, position and linearity of these ridges suggests a link with the Cobandede fault zone at the eastern end of the basin. This fault zone, by association with the linear Dumlu fault zone marking the western end of the basin, probably experiences a significant component of left-lateral displacement. On this interpretation the linear ridges near Köprüköy may represent contractional, right-stepping, transfer zones between en echelon fault traces within the Cobandede fault zone (Fig. 2).

V. River terraces:

Fluvial deposits cover much of the basin floor, underlying a series of alluvial surfaces. In the west of the basin, three main terraces occur above the floodplain (Collins *et al*. 2005). Only the highest terrace (zone Va on Fig. 3) can be differentiated on the DEM in the western part of the basin, where it is mainly less than 10m above the channel. It has a surface gradient of 1.1-1.3 m km^{-1}, comparable to many of the alluvial fans. Indeed, it may well represent deposition under former hydrological conditions that were similar to the fans, probably under a Late Pleistocene cold climate. Exposures along the Çaykara channel, east of Uzunahmet, indicate dominance by high magnitude floods, while more proximal deposits north of Çeperli include hyperconcentrated flow and mudflow units.

The second terrace is of limited extent and no information is available on the underlying sediments. Sand, silt, and sparse gravel, representing episodic overbank deposition, with some channel sediments, during the Holocene, underlie the lowest terrace. The floodplain formed in the last few centuries (Collins et al. 2005). The lowest terrace and floodplain locally have gradients of up to 1.2 m km^{-1}, but mainly the rate of surface fall is well below 1.0 m km^{-1}, and sometimes as low as 0.2 m km^{-1}. The steeper slope of the highest terrace means that the sediments that underlie it merge with, and are possibly buried by sediments of the lower terraces.

The absence of higher terraces suggests that much of the basin's recent (i.e. Late Pleistocene) fluvial history has been dominated by valley filling. Sediment supply to the basin may be controlled by tectonics, and particularly seismically triggered slope failures. The redistribution of this sediment across the lower gradient basin floor is dominated by climatic controls as the series of environmental changes preserved in the deposits can be correlated with sites across the region (Collins *et al.* 2005).

Drainage

The basin's drainage exhibits an elongated dendritic pattern (Fig. 2). East of Pasinler, most tributary streams join the main channel at an obtuse angle due to the lower gradient. West of Pasinler, confluence angles are acute, reflecting steeper gradients (Fig. 3). In this western sector of the basin, three main tributary systems merge over a few hundred metres immediately upstream of Pasinler. The central tributary is the largest, collecting water from much of the western half of the basin. The southeastern tributary flows out from the southern mountains, while the northeastern tributary mainly derives its water from the northern mountains above Porsuk. Channel gradients in this northern tributary are high as it passes down the Porsuk landslide, up to 200 m km^{-1} though with significant variations reflecting the landslide's chaotic relief, then abruptly decline at the end of the landslide, reaching a minimum of 2.5 m km^{-1}. The gradients of the southeastern and central tributaries both show a steady upstream increase, with the southeastern tributary steepening more rapidly, reflecting its smaller catchment.

Several channel planforms are present in the basin. East of Pasinler, the basin's axial drainage channel is meandering (sinuosity 0.4-1.4). Multiple large meandering palaeochannels are present on the floodplain and lowest terrace east of Pasinler, suggesting less variable flow in the past. In the western sector, most channels have low sinuosity and feature gravel bedforms. A significant exception to this is immediately west of Pasinler where the central and especially the northeastern tributary channels become highly sinuous (sinuosity 1.9). The available map survey data suggest the northeastern tributary is some ten metres lower than the southeastern tributary in this part of the valley floor, possibly reflecting subsidence.

Two types of drainage pattern modification have occurred in the thrust belts on the southern margin of the basin floor, west of Alvar (Zone IVc), reflecting the extent of back tilting and variations in stream energy. The first is entrenchment, where the streams have been able to incise at the same rate as back tilting. The second type is diversion, leading to offset and abandoned channels (Fig. 2).

Discussion

Controls on mass movement processes

All the mass movements observed in the Pasinler Basin are related to faults, indicating the importance of tectonic activity, both in providing discontinuities exploited as landslide failure planes and through seismic shaking. It seems probable that seismic events have been the dominant trigger, though climatic controls such as infiltrating water may have been locally significant (*cf.* Hürlimann *et al*. 2000).

In the case of the landslide complex centred on Porsuk, rapid relative uplift of the plateau during the Pliocene provided structural and morphological conditions suitable for the subsequent series of large mass movements. Initial movement of material is thought to have been through a mixture of free fall and sliding. As the debris reached the lower slopes it then adopted the characteristics of a flow, with movement probably aided by trapped air and water. The steep front of the flow complex suggests a sudden increase in friction, which accords with the abrupt grounding of the debris at the basin margin. This indicates the sudden loss of a low viscosity basal lubricating medium, though it s not yet clear if this was air or water.

Mass movements on the basin's southern margin are much smaller (typically a few tens of metres across) than those on the north. Thrusting is clearly affecting this area, as evidenced by the large lobate landforms, apparently recent changes in drainage, and faults exposed in road cuts and may mark the first stages of steepening of these areas.

Tectonic transition

The largest mass movements, at Porsuk and Büyuk Tuy, postdate the formation of the Erzurum-Kars Plateau in the Pliocene and can only have formed after substantial relative uplift of the plateau had occurred. Boulders on the surface of the mass movement complex near Porsuk and Yiğittası are intensely weathered, suggesting prolonged exposure. Significant tectonic deformation and dissection of the complex also suggests a long period since its emplacement. Although it is not yet possible to provide a firm estimate of when the mass movements occurred, their current condition and relation to known older features implies a late-Pliocene to Quaternary age.

In comparison with the large mass movement complexes, most landforms associated with thrusting appear less degraded and, hence, younger. Indeed reverse faults cut late Quaternary alluvial fan deposits in several places around the basin margins. In addition, the difference in river channel elevations in the area west of Pasinler, with the lowest on the northern side of the basin floor, suggests localised downwarping at the base of the mountain front, perhaps due to a thrust-driven fold.

The implication of this is that the basin has undergone a series of major changes in tectonic stress regime, recorded by its landforms and associated sediments. Three phases (with approximate ages) can be identified:

Phase A (Miocene-Pliocene): volcanism associated with extension and strike-slip faulting;

Phase B (Pliocene-Early Quaternary): end of extensional volcanism, onset of differential plateau uplift;

Phase C (Late Pliocene-Early Quaternary: basin floor subsidence associated with normal faulting, large mass movements on northern basin margin, incision and deposition;

Phase D (Middle Quaternary-present): onset of compressive stress regime within the basin associated with warping of plateau surfaces, thrust faulting at the basin margins and ongoing subsidence and deformation of the basin floor.

The geomorphologically-indicated shift in stress regime accords with a roughly west to east migration of local extensional zones along the North East Anatolian Fault system, with the location of active volcanic centres progressively shifting away from the Pasinler areas sometime after about 5.6 Ma, ending in the Kagizman area (c. 100 km east of Pasinler) around 2.7 Ma (Keskin *et al.* 1998). The evidence for a significant change in the tectonic stress regime within the basin, probably in the Pliocene to Early Quaternary, may coincide with changes elsewhere in the region, for example along the East Anatolian Fault (Over *et al.* 2004a, b). The limited dating control from Pasinler means that it is not possible to be certain of exact synchronicity. It does seem likely, however, that onset of significant westwards movement of the Anatolian microplate induced major tectonic and landscape response across the region. The Quaternary volcanoes Nemrut, Suphan, Tendurek and Ararat may also reflect this migration (Yılmaz *et al.,* 1998; Karakhanian *et al.* 2004).

Conclusions

The series of morphological zones of the Pasinler Basin are identifiable through the combination of traditional methods such as detailed field survey with the use of remotely sensed information, in particular the SRTM-DEM elevation data. The zones identified reflect varying degrees of tectonic deformation, either ongoing, or occurring under differing tectonic stress regimes in the past. At the margins, pronounced deformation has produced progressive surface modification and, in places, induced catastrophic change in the form of large volume mass movements. In the centre of the basin, deformation is more limited and variations in recent sedimentation appear climatically driven.

The landforms and sediments, linked to earlier studies on the igneous geology of the basin, indicate a series of changes in the nature of tectonic movements in the basin since the Miocene. The initial transtensional regime was replaced by a normal faulting regime in the Pliocene-Early Quaternary. The present-day tectonic regime is dominated by thrusting within the basin, while strike-slip movements occur at the basin margins. These changes appear to relate to a shift in regional tectonism associated with the initiation of the Anatolian microplate's westwards movement.

Of some significance is the degree of preservation of ancient landform features in the Pasinler Basin, despite intense tectonic activity in the geologically-recent past. This has major implications for our understanding of landscape evolution in the region as it demonstrates that geomorphological activity at any point in time is focussed on specific locations. In the case of the Pasinler Basin, such activity is largely determined by past and present tectonic processes that provide both the physical framework and the energy for change.

Acknowledgements

Fieldwork was supported by Brunel University and Atatürk University. Thomas Dewez, BRGM, FRANCE, kindly provided initial and important assistance with the DEM. Ian Roberts, Anthony Sagona, Jenny Reid, and Iain Stewart are thanked for invaluable discussions. Richard Collier, an anonymous referee and the Editor, Jamie Woodward, are thanked for their extremely helpful comments. The Mayor and people of the Pasinler area are thanked for the hospitality and support they gave the authors during the field data collection.

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Geomorphological evidence for a changing tectonic regime, Pasinler Basin, Turkey.

Figures captions

1. Turkey and adjoining countries, showing major rivers and the location of Pasinler (marked by large 'P', east of Erzurum)
2. The Pasinler Basin. Top: major surficial deposits, channel network and landslide features. The two circles show where significant drainage diversions mentioned in the text have occurred, near Alvar and affecting a possible former route of the river Aras into the Basin. Bottom: Faults, superimposed upon channel network, with fault orientation by cumulative length. The cross-section lines
3. Digital elevation model of the Pasinler basin using SRTM data (GLCF 1997-2005). A) greyscale elevation plot with overlay showing the main geomorphological zones – Ia-c: Plateau; II: major alluvial fans; III: major mass movement complex; IV: thrust-deformed areas; V: river terraces. B) Slope plot highlighting areas with steeper gradients (>10 º).
4. Cross-sections of the Pasinler Basin, showing the main lithologies (after MTA 1988) and faults. Transect lines are shown on Fig 2. Elevation is from SRTM data. Top: Transect A-B, showing the northern and southern margins; bottom: Transect C-D, showing the northern margin at mass movement scar L4.
5. Surface of zone III (mass movement complex) and zone Iva (in background). Note the large weathered boulders in foreground and the irregular form of the mass movement complex.

6. Road-cut exposure of Pleistocene fluvial deposits within zone IVc (deformed southern margin), featuring a thrust fault and, inset, chevron folding. Note vehicle and figures at bottom left, for scale).

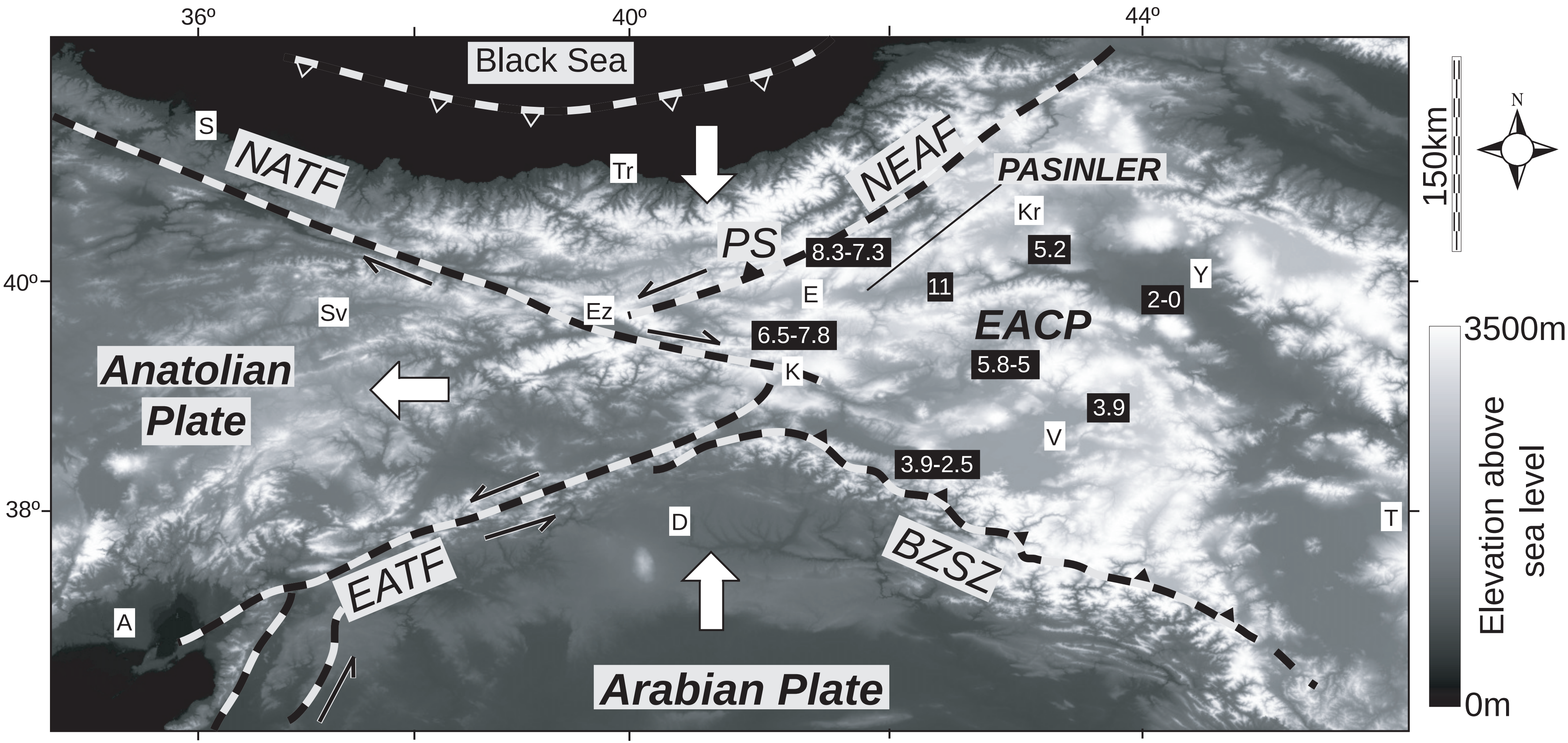
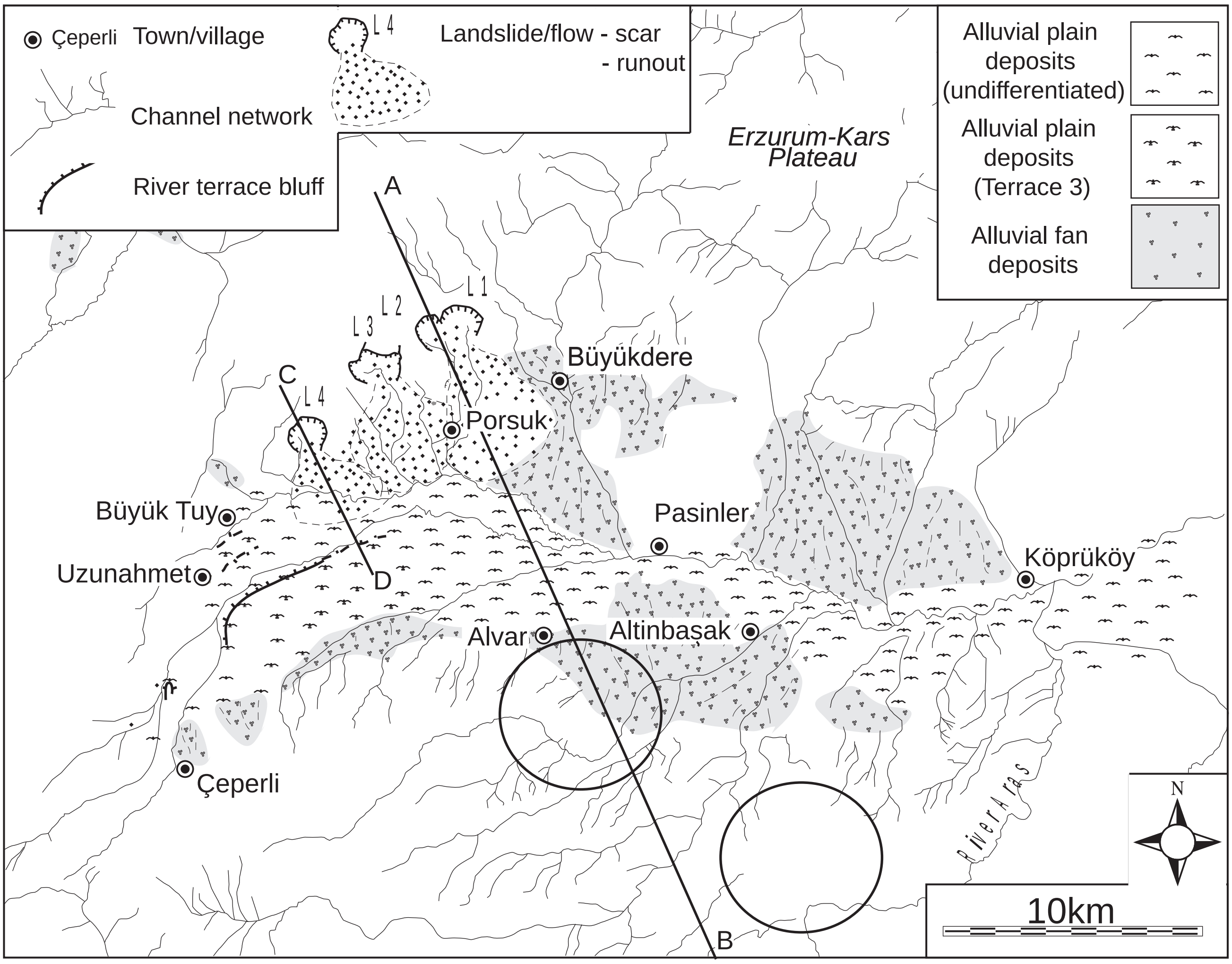
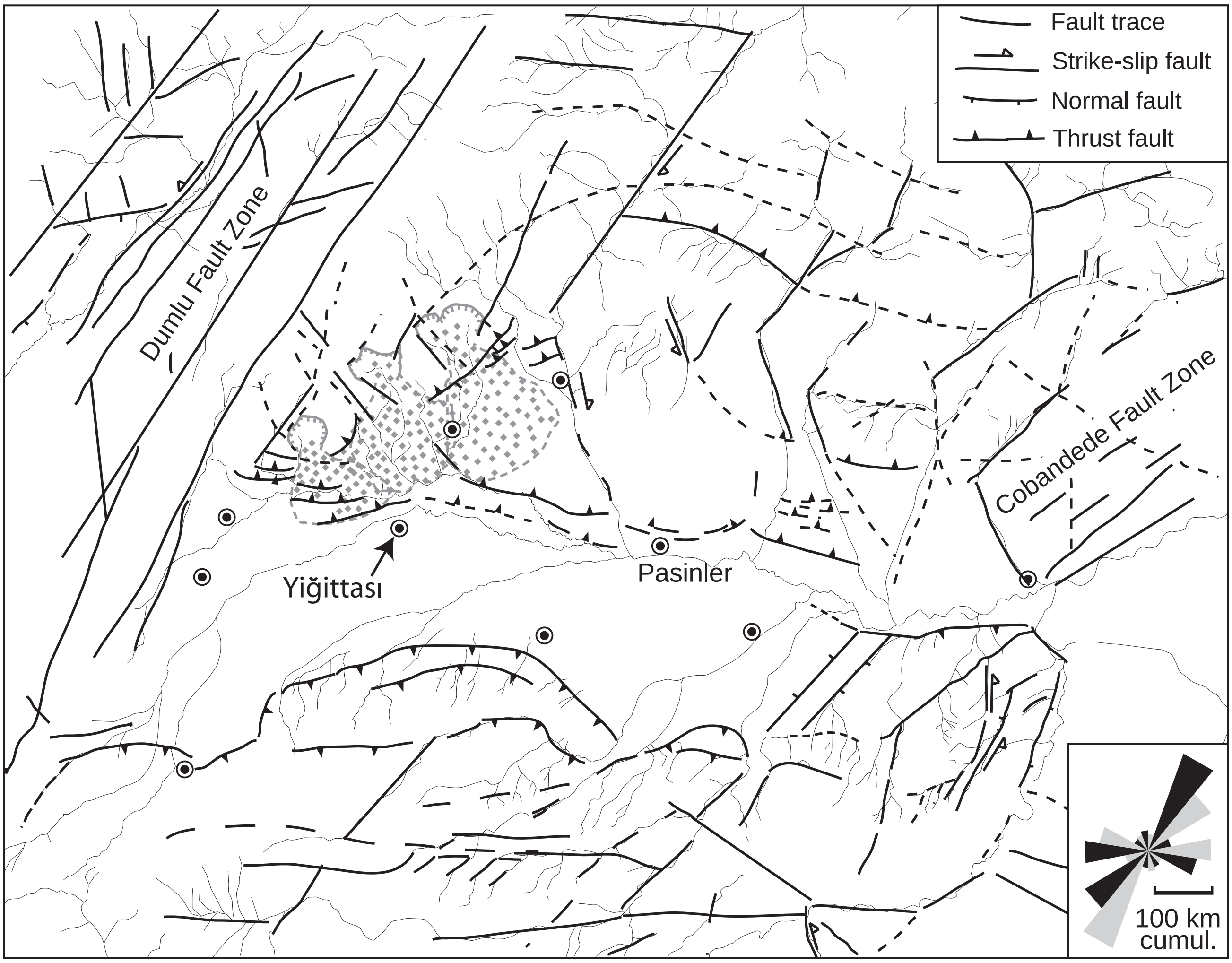
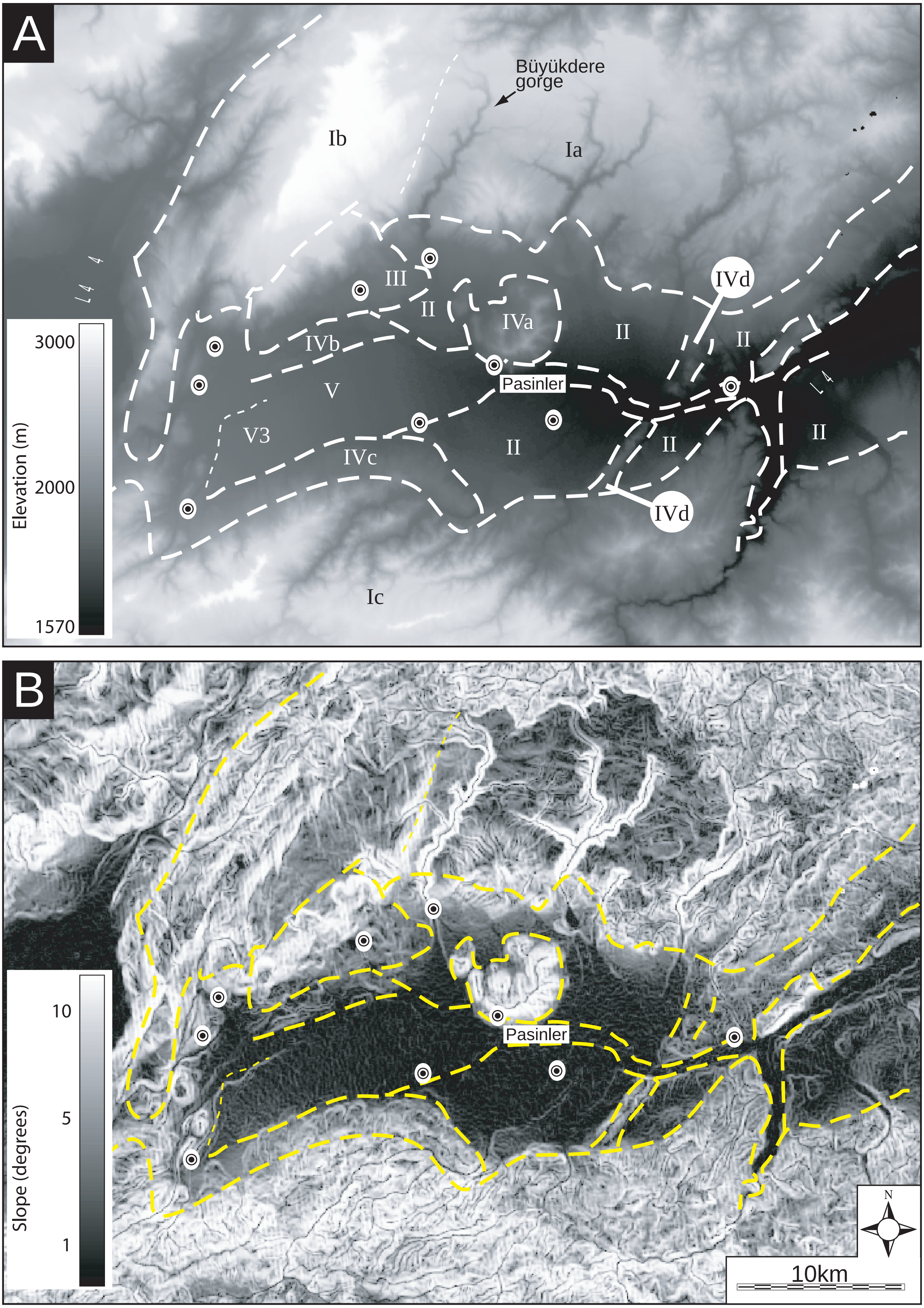


Fig 1:
Regional DEM derived from SRTM GTOPO data (GLCF 2006) showing the location of the Pasinler Basin and major tectonic lineations (after Dewey et al. 1986, Bozkurt, 2001,Elmas, 2003, Keskin 2003).
EACP=East Anatolian Contractional Province; NATF-North Anatolian Transform Fault zone, PS-Pontide Suture. Large white arrows indicate generalised relative tectonic movement .
Locations: A-Adana, D-Diyarbakir, E-Erzurum,Ez-Erzincan, K-Karliova, Kr-Kars, S-Samsun, Sv-Sivas, T-Tabriz, Tr-Trabzon, V-Van, Y-Yerevan. Numbers in back squares indicate
the estimated initiation of volcanism, based on Keskin 2003.


Çeperli Town/village
Channel network
River terrace bluff
Landslide/flow - scar
- runout
L 4
Alluvial plain deposits (undifferentiated)
Alluvial plain deposits (Terrace 3)
Alluvial fan deposits
Erzurum-Kars Plateau
A
B
C
D
L 1
L 2
L 3
Büyükdere
Porsuk
Büyük Tuy
Uzunahmet
Pasinler
Köprüköy
Alvar
Altinbasak
Çeperli
River Aras
N
10km


Fault trace
Strike-slip fault
Normal fault
Thrust fault
Dumlu Fault Zone
Cobandede Fault Zone
Yiğittası
Pasinler
100 km
cumul.


A
Büyükdere gorge
Ib
Ia
III
II
IVa
IVd
IVb
V
Pasinler
V3
IVc
Ic
3000
2000
1570
Elevation (m)
B
Pasinler
10
5
1
Slope (degrees)
N
10km

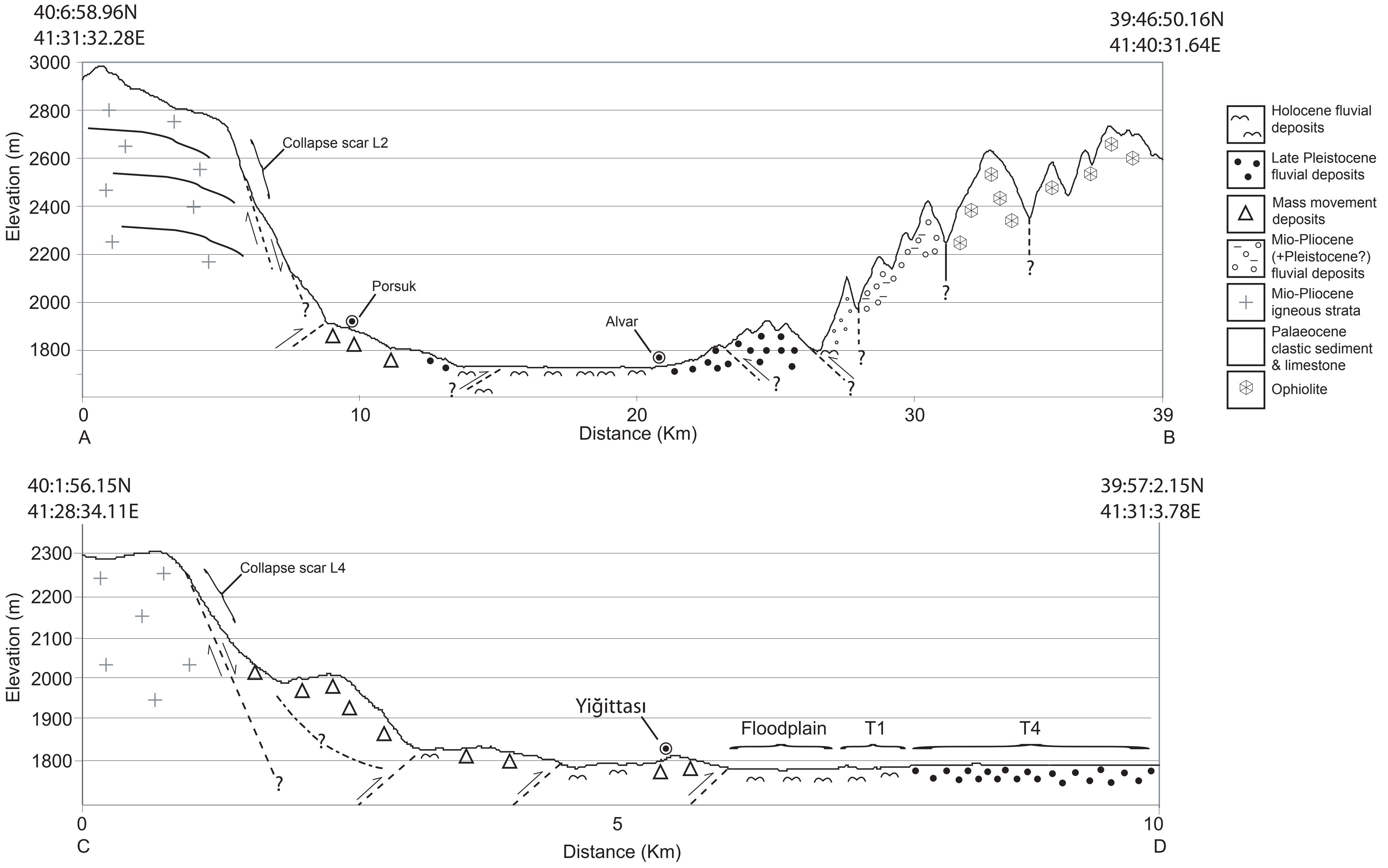
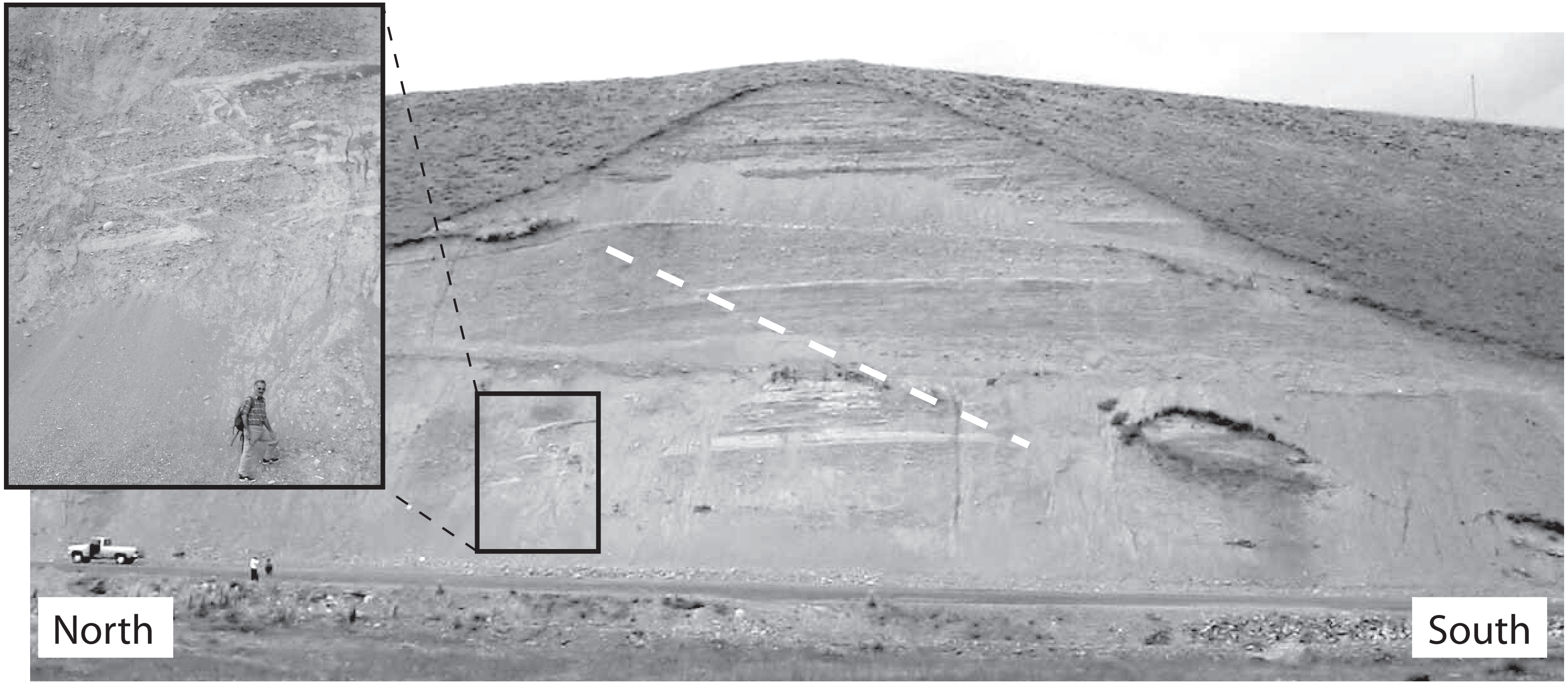


Fig 4. Cross-sections of the Pasinler Basin, showing the main lithologies and fault. Transect lines are shown on Fig 2. Elevation is from SRTM data. Top: Transect A-B, Showing the north and south margins; bottom: Transect C-D, showing the north margin at mass movement scar L4.


Warped margin of Erzurum-Kars Plateau (zone Ia)
Zone IVa back-tilted block
Pasinler


North
South