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SMALL SCALE CONTRACTIONAL - EXTENSIONAL STRUCTURES AND MORPHOTECTONICS ALONG THE FAULT TRACES OF IZMIT-KOCAELI (TURKEY) 1999 EARTHQUAKE

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ABSTRACT

The Mw=7.4 Izmit (Kocaeli) earthquake of August 17, 1999 (Turkey) ruptured 100 km at least surface faults on land along the northwestern branch of the North Anatolian Fault Zone (NAFZ). Although the pre-existing structures of NAFZ has been divided into segments, showing stepover and pull apart geometry, the earthquake ruptures are generally linear, E-W striking (N80°-100°), right-lateral. In small scale and on the recent sediments they show very typical strike-slip displacements (2 to 5m), pop-ups and pressure ridges (N 40-70°), P (N80°), R (N100-110°) and R′ (~N350°) Riedel shears, extensional cracks (N115°-135°), restraining and releasing bends and small pull apart structures. In the epicentral area (Gölcük-Tepetarla) the seismic ruptures did not follow any known or previously mapped fault, but the morphology and the Digital Elevation Model (DEM) show typical and recognizable paleo-earthquake features. That is elongated valleys, shutter ridges, high angle slopes, scarplets, stream offset; while trenching tectonostratigraphy indicate palaeo sag-ponds (clayly deposits) and palaeo liquefaction (C^{14} dating-Holocene-historical deposits 200 to 11,000 yr. BP).

ΠΕΡΙΛΗΨΗ

Ο σεισμός της 17ης Αυγούστου 1999 στην Τουρκία (Mw=7.4) έδωσε επιφανειακές διαρρήξεις περίπου 100 km στην ξηρά από την πόλη Gölcük μέχρι τη λίμνη Eften. Με βάση γεωμετρικά κριτήρια το σεισμικό ρήγμα μπορεί να διακριθεί σε δύο κύρια "τμήματα" με γενική γραμμική διάταξη και δεξιόστροφη κίνηση. Από τη μελέτη μικροδομών κατά μήκος του ρήγματος, όπως εμφανίζονται επιφανειακά στα πρόσφατα ιζήματα, προκύπτει ότι η γενική διεύθυνση του είναι Α-Δ (80-100°), οι δεξιόστροφες οριζόντιες μετατοπίσεις φτάνουν τα 2 έως 5 m, οι συμπιεστικές δομές αναπτύσσονται σε διευθύνσεις 40-70°, οι συνθετικές Riedel διατμήσεις σε 80° (P) και 100-110° (R), οι αντιθετικές σε 350° (R′) και οι εφελκυστικές 115-135°, δηλαδή τυπικές ιδεατές δομές μια απλής δεξιόστροφης διάτμησης. Στην επικεντρική περιοχή του Goltcuk-Tepetarla οι διαρρήξεις ακολουθούν τυπικές μορφολογικές δομές, όπως προκύπτει από την τριδιάστατη ανάλυση του αναγλύφου (DEM) και την τεκτονοστρωματογραφική ανάλυση παλαιοσεισμολογικών εκσκαφών(παλαιορευστοποιήσεις εδαφών:C^{14} 200 μέχρι 11,000 χρόνια-Ολόκαινο).

KEY WORDS: Co-seismic ruptures, Earthquake structures, Izmit-Kocaeli earthquake.

INTRODUCTION

Field observations along the 90-100 km on land fault traces of the Izmit (Kocaeli) 17th August, 1999 earthquake have been taken immediately after the event (Tutkun et al. 2000) and on the small scale structures (tension fractures, contractional, Riedel shears) in detail, on May 17 and mainly June 17-20, 2000. The earthquake caused right-lateral strike-slip movement on the fault. The surface ruptures are named as Karadere-Arifiye and Sapanca-Gölcük "segments" from east to west as a first approximation (fig.1). To the west the rupture might extend under the Izmit gulf for over 50 km. The total measured on land maximum offset range between 1 and 4.8 m on the Karadere-Arifiye segment and 2.5-3.5 on the Sapanca-Golcuk segment.

Although many papers, announcements and abstracts have appeared recently on the Izmit fault traces geometry and kinematics, little attention has been paid subsequently to the small-scale structures associated with divergence or convergence or simple shear along the activated seismic fault. They constitute a useful point of analysis of structures along strike-slip faults and could be helpful for considerably larger scale (fig. 2). They are analogues to the North Anatolian Fault Zone itself.

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The purpose of this paper is to summarize the 1999 fault geometry and segmentation and to emphasize both on some small-scale typical strike-slip characteristics and controls on superficial structural patterns within the sedimentary cover and to morphotectonics of the pre-existing active fault.

FAULT GEOMETRY AND SEGMENTATION

Although the earthquake ruptures are generally linear (fig. 1), E-W striking (N80°-100°), they can be divided into segments on the basis of their geometry. The Karadere "segment" (or branch) (A) is an ENE-WSW (N75-85°) striking, 20-25km (?) long fault from Eften lake to Akyazi town, it also overlapped with the November 12, 1999 Duzce earthquake ruptures (Emre et al., 2000); the maximum observed displacement was about 2m, while the average less than 1m. The Arifiye "segment" (B) is a 25 km long linear and more or less continues seismic trace from the Arifiye village to the east shore of the Sapanca lake. In between Arifiye and the town of Akyazi there is a 5 km gap of surface seismic traces. It strikes E-W (90°). The maximum right lateral displacement (4.8 m) was observed close to Arifiye village. The displacement is gradually decreased toward the east (0.3m), but the average displacement on this segment is as high as 2-2.5m. The Karadere and Arifiye fault branches are sub-parallel and near to the western edge of the 1967 Mudurnu seismic fault traces (Ambraseys & Zatopec 1969, Barka & Kadinsky-Cade 1988). This segment is separated from the Sapanca-Gölcük one by the Sapanca lake step over and by a NW-SE trending normal fault(Gölcük peninsula-Kavakli area).

The Sapanca-Tepetarla-Gölcük E-W (90^0) striking, 35km long "segments" (C) extends from the northwestern shore of the lake Sapanca to Gölcük peninsula, while for about 4 km it runs under the Izmit gulf along the southern shoreline. The maximum displacement is 4m, while the average is 2.5 ± 0.5m. The western edge of the segment at Kavakli area is a normal (2.10m) right-lateral (0.2-0.3m) oblique slip 5 km normal fault, NW-SE (120-130^0) striking.

The Western "segment" (D) is a possible submarine E-W structure from Golcuk to Yalova about 40-50 long. It is simply based on spatio-temporal distribution of aftershocks. The seismicity pattern itself defines two (2) segments that extend about 80km east and 75km west of the mainshock epicenter (40.8N-29.9E, Gölcük-Izmit, fig.1). For further information on the fault geometry see also Awata et al, 2000; Barka 1999, 2000; Tutkun 2000; Youd L. et al "Eq SPECTRA" 2000, Lekkas 2001, Ergin et al. 2001 among others.

SMALL-SCALE STRUCTURAL PATTERNS

Although the observed ruptures are pure strike-slip mainly, drag faults are often seen with pressure ridges, tension fractures and small pull apart basins (Biddle & Christie-Blick 1985). The most remarkable normal fault was found in Kavakli area (Golcuk peninsula). It is a WNW-ESE trending, NNE dipping oblique-slip fault. At Kavakli sport center it shows 130-140° strike, 1.5m vertical displacement and 0.3m dextral one. It is a typical extensional feature perpendicular to σ_3 main stress principal axis. Extensional features, which are mode I cracks, form in strike-slip systems, in response to simple shear at about 45^0 to the master fault. This normal fault is possibly the visible strand of a pull-apart structure.

Co-existence of strike-slip faults with normal and reverse separation is typical (Biddle & Christie-Blick 1985, see also Scholz 1990). Compressional small scale structures observed are: pressure ridges, that is linear topographic highs bounded by faults, and pop-ups, that is uplifted small block, as well as trusts at 40°. In general the orientation and movement along right-stepping small fault branches has resulted in local compression that caused shortening and uplift. Figure 2 (a) and (b) shows typical reverse structures (40-70°). On the contrary in local extension tension fractures have been developed at 130-130° mainly, that is 40 to 45° to the master fault. Synthetic shears (R) Riedles stand at 100-110^0 and (P) shears at 80^0, while in 170^0 stands the antithetic (or conjugate Riedle R´) shear and the Main right-lateral Displacement Zone at 90^0, (fig.2).

MORPHOTECTONICS

Earthquake geology recently developed the study of Earth's surface (morphotectonics) for evidence of earthquake faulting. The most impressive morphotectonic structures in the region, which dominate the area, are the E-W elongated Gulf of Izmit, the lake Sapanca and the Tepetarla-Arifiye elongated too, valley. The gulf is in fact a 50km long and 10 average width prolongation of the sea inland, along the northwestern branch of NAFZ (see also fig. 1). In smaller scale the Tepetarla-Yaylacik morphology has been studied in detail by topographic sections, DEM construction (ARCINFO and ARCVIEW) and consequently landscape analysis, as the most typical example of the region. Both morphology and Plio-pleistocene deposit stratigraphy indicate the fault migration northwards (fig. 3) up to linear E-W elongated valley where the 1999 ruptures appeared.

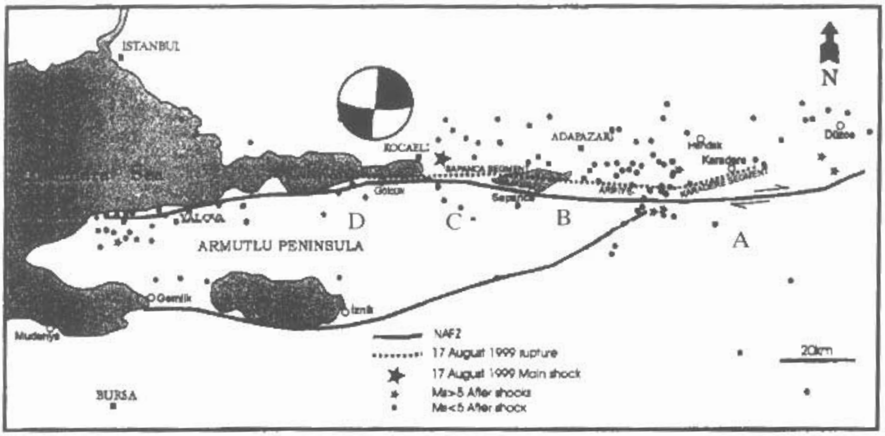
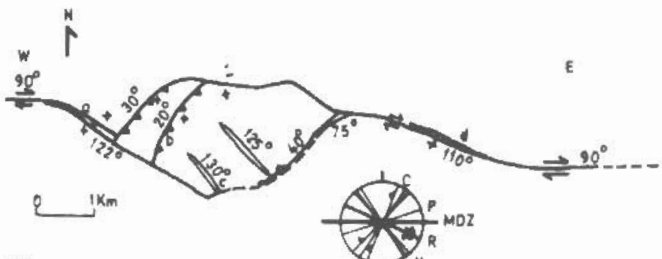
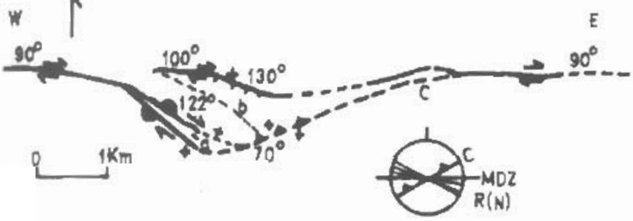


Fig. 1. The surface ruptures of the 17th August 1999 (Mw=7.4) Izmit earthquake with the four distinct "segments" (or branches) named from east to west: A. Karadere; B. Arifiye; C. Sapanca-Golcuk; D. Izmit Gulf. In general the co-seismic fault ruptures are linear and could be divided into two typical segments. NAFZ: North Anatolian Fault Zone (western strands), (after Z. Tutkun et al 1999, 2000 unpublished).



(A)



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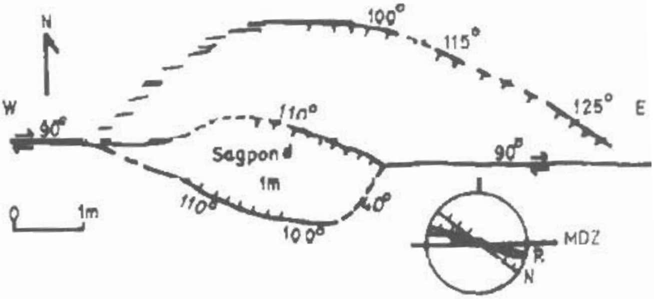

(C)

(D)

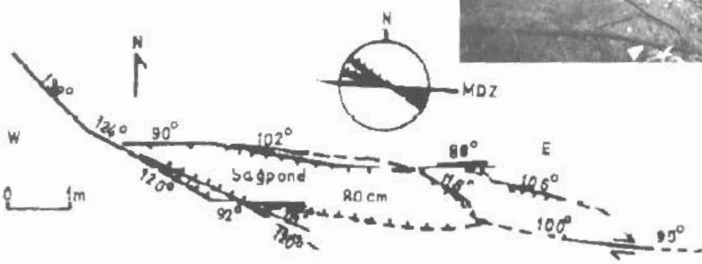

Fig. 2. Representative detailed mapped small scale features along the right-lateral strike-slip Izmit co-seismic fault. A) Geometry of a Pressure Ridge at Tepetarla and the angular relation among structures (small circle), MDZ: master Displacement Zone, C: contractional structures, N: normal or Tension fractures, P and R shears; right the corresponding photograph. B) Displaced poplar (kavak) at Tepetarla, diagram in map view, at a: strike-slip displacement D=37cm, Opening O=28cm; at b: D=10cm, vertical Displacement D′=60cm, O=35cm; right the corresponding photograph. C) and D) Sag-pond geometry at Arifiye (sketches and photographs).

Several neotectonic and geomorphic observations along the fault indicate Quaternary activity. Yavlacik hill (a) where the new apartment buildings on the fault trace totally collapsed, is a typical shutter ridge, which controls the drainage diversion. The "Mahmut pasa ciftligi" can be also characterized as a large scale elongated E-W shutter hill (b) the most characteristic small shutter ridge is the10m long (E-W) and 3m width (c) in the center of the E-W elongated small valley, southern of "Mahmut pasa" hill, along the recent seismic traces (fig. 3).

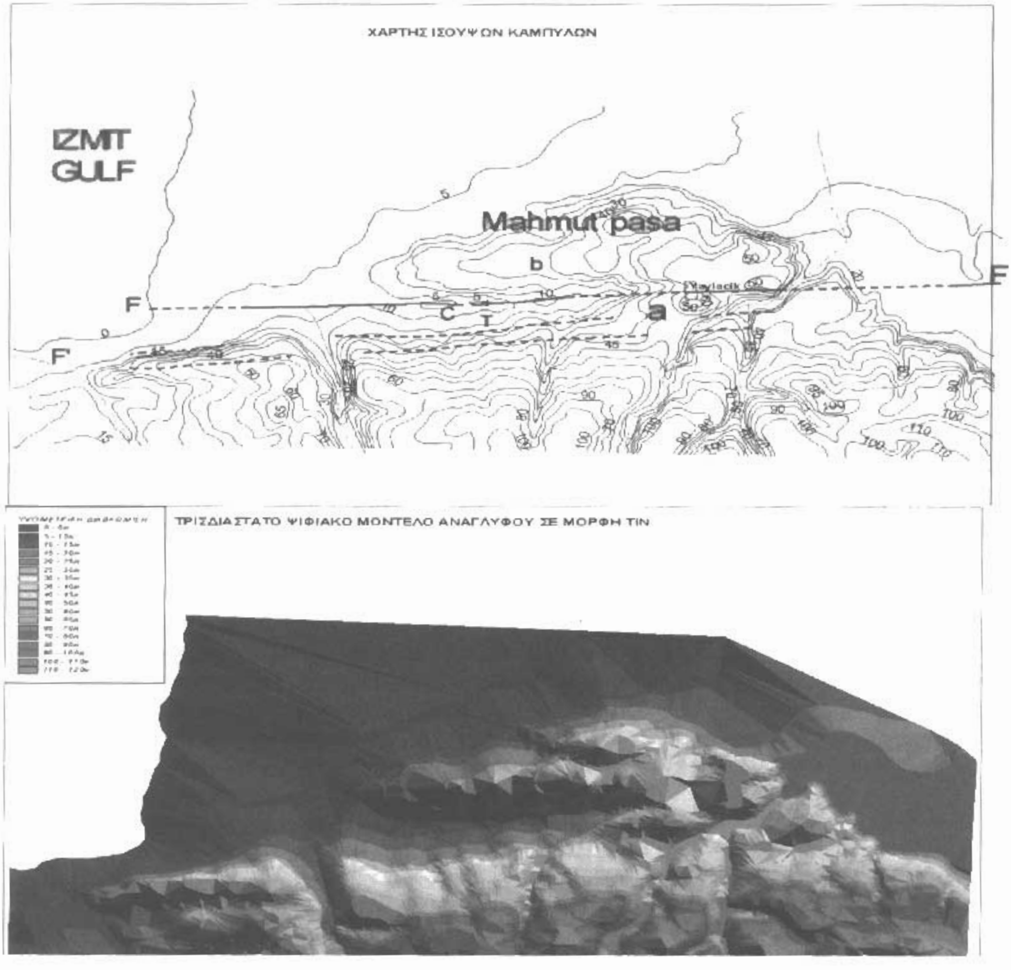

Fig. 3. Top: Topographic map part of Sapanca-Gφlcók segment at Mahmut pasa ciftligi (between Yaylacik and Yuvacik villages) F: 1999 co-seismic fault traces; F': pre-existing faults (in geological terms); a,b,c : shutter ridges; T: trenches. Down: Digital probable Elevetion Model (DEM) of the landscape at the same area.

We have begun a programme of trenching across the fault in order to obtain fundamental data for the evaluation of past activity. Two trenches on the fault traces have been excavated (fig. 3; T), 8m long and 4m deep in order to look for paleo fossilized seismic structures or paleo-earthquakes (fig. 4). They show three at least layers and the superficial recent soil, named a) 2m thick dark soil; b) 1m yellow sandy mad, possibly of paleo sag ponds deposits, and c) 1m dark paleo soil with few pebbles. They are in typical horizontal position, but disaccommodated. Structural features, that is joints (cracks), seismites and paleo-liquefaction, associated with the fault and identified from sampled and C14 dated. This fault segment is possibly associated with the 1894 and 1878 earthquakes (Papadimitriou et al 2000; Ambraseys 2001), as well as with the strong shocks of the 18th century (1719 and 1754).

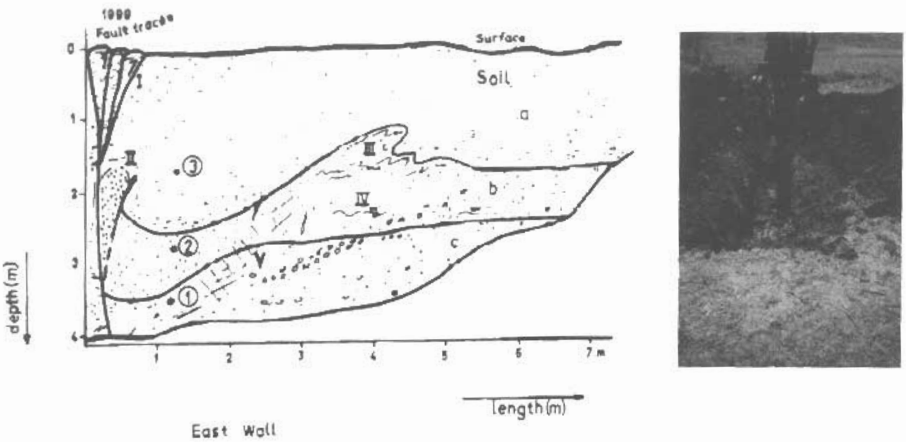

Fig. 4. Trench (Izmit-I, East wall) where the three distinct layers are shown (a: soil; b: sandy mad (clays); c: soil, possibly of palaeo-sag-pond origin), the 1999 fault (contactional) with the small-scale flower structure (I), liquefaction (II and III), seismites (IV) and cracks (V). Sampling sites 1: 11,800 +-40 years BP; 3:120+-40 years BP (Radiocarbon Analysis, The University of Georgia, USA) Photograph: excavation works.

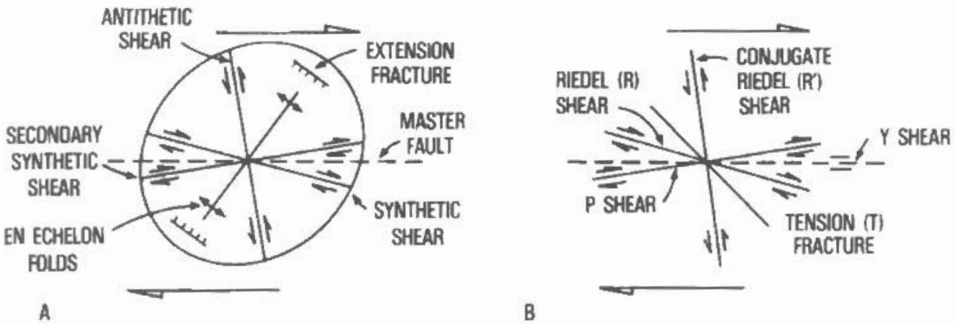

Fig. 5. The angular relations between structures in right-lateral simple shear conditions (Biddle & Christie-Blick 1985) that tend to form the measured small and medium size structures of the 1999 Izmit earthquake surface fault traces.

CONCLUSIONS

The co-seismic rupture is not a single break, instead it is composed of numerous small scale structures 2 to 10 m long, that is tension fractures and contractional structures, e.g. pressure ridges, pop ups, sagponds, and Riedel synthetic shears controlled by the master fault displacement were studied. Some representative measurements and the corresponding sites are given in the figure 2. Reasonable and quantitative explanation for the observation that either subsidence or uplift takes place, is given. Primary structures on the sedimentary cover along the activated 1999 fault are close to those predicted by an idealized strain ellipse for right lateral shear (fig. 5). They are analogues to the North Anatolian Fault Zone. In macro scale and on the base of surface geometry, the total length of the 1999 Izmit fault can be divided into two main segments and some shorter slightly overstepping branches. Representative morphotectonic and trenching tectonostratigraphy at Sapanza-Gφlcók segment clearly show the Holocene-historical (200 to 11,000 years BP C14) development of the fault at the present site.

 

Fig. 6. Left (a) Normal fault subparallel (strike N 106°) strand to Gφlcök -Sapanca "segment" (Asagiyuvacik) with vertical displacement of 40 cm. This strand is lying 50 m southern to master dextral displacement fault where D was 1.10-1.20 m horizontal. Right (b). The right – lateral fault zone at Tepetarla D=1.20 m.

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TABLE I. Representative measurements of small scale features along the right-lateral strike-slip Izmit co-seismic fault. All measurement are given in degrees from North (strike). MDZ: Master Displacement Zone; P and R Riedel Shears; Ex: Tension fractures-normal faults; C: Contractional (compressional) R' shear (antithetic); Dh: horizontal (dextral) Displacement; Dv: vertical and H: heave (opening)

Göltcuk-Kavakli-FORD

MDZ	P	R	Ex	C	R'	Dh	Dv	H
90°	-	-	-	-	-	3.50	-	-
90°	-	-	125°	-	-	0.20	1.80	-
-	-	-	130°	-	-	0.30	2.00	-
-	-	-	140°	-	-	-	-	-
-	-	-	135°	-	155°	-	-	-
-	-	-	130°	-	170°	0.30	1.50	-
82°	-	-	-	-	-	0.90	-	-
85°	-	-	-	-	-	2.60	-	-
90°	-	-	-	-	-	2.80	-	-

Tepetarla

MDZ	P	R	Ex	C	R'	Dh	Dv	H
90°	-	100°	130°	40°	-	0.10	0.60	0.35
90°	80°	-	122°	70°	-	0.37	-	0.28
90°	-	-	132°	55°	-	-	0.30	-
90°	-	-	122°	30°	-	-	0.80	0.10
90°	-	110°	130°	20°	-	-	-	-
90°	-	105°	115°	-	-	-	-	-
100°	-	110°	-	70°	-	-	-	-

Asagiguvacik village (Göltsu-Izmit area)

MDZ	P	R	Ex	C	R'	Dh	Dv	H
90°	82°	105°	130°	-	-	2.5	-	-
94°	88°	(110°)	120°	-	-	2.5	0.80	-
96°	-	-	115°	-	-	-	0.60	-
100°	-	-	120°	-	-	-	0.42	-
			130°				0.55	

Mustapha pasaYaylacik

MDZ	P	R	Ex	C	R'	Dh	Dv	H
100°	-	110°	125°	50°	-	2.3	-	-
100°	-		125°	40°		-	-	
85°	-	110°	130°	40°	-	-	-	0.1
90°	-	115°	140°	43°	-	-	-	-
90°	80°	110°	135°	-	170°	-	-	0.2
90°	-	115°	140°	50°	-	-	-	0.18
90°	78°	106°	120°	55°	-	-	-	-
100°	-	110°	122°	70°	-	-	-	0.30
90°	80°		124°	60°	-	-	-	
95°	80°	-	130°	-	185°	-	-	-
92°	80°	-	120°	-	-	-	0.42	-

Sapanca-Arifiye

MDZ	P	R	Ex	C	R'	Dh	Dv	H
105°	-	135°	125°	50°	-		0.10	-
90°	-	120°	125°	40°			-	1.50
92°	-	102°	124°	-	-	-	0.80	-
88°	-	106°	138°	-	-	-	0.40	-
95°	80°	114°	125°	-	-	-	0.45	-
90°	-	110°	128°	-	-	-	1.00	-
90°	78°	110°	130°	-	-	-	-	-
90°	-	115°	135°	-	-	-	0.50	-
90°	80°	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-