2-14: Yakeng detachment fold, South Tianshan, China

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Location: Kuche, Tarim Basin, Xinjiang, China
Topic: Analysis of a detachment fold in the thickness domain
Reserves: Exploration region

Key Point: Yakeng anticline illustrates the importance of working in the thickness domain when interpreting detachment folds. Measurements in the thickness domain show that Yakeng has 1.2 km shortening above a basal two levels of major detachment, basal diapirism, basement folding, and a 2.4-km-thick growth sequence.

Structural Setting: The active Yakeng anticline is topographically expressed by deformation of the alluvium at the front of the southern Tianshan thrust belt (Figure 1). Seismic imaging and drilling (Figure 2) show it to be a classic detachment fold lying above a decollement in the evaporite-rich Tertiary Jidikuh Formation, which roots northward (below horizon 4) into the massive 200-km-long Quilitak anticline (Figure 1). Just to the south of Yakeng anticline is the Yanan anticline, which is a basement-involved inversion structure whose north flank interferes with the south flank of the Yakeng anticline.

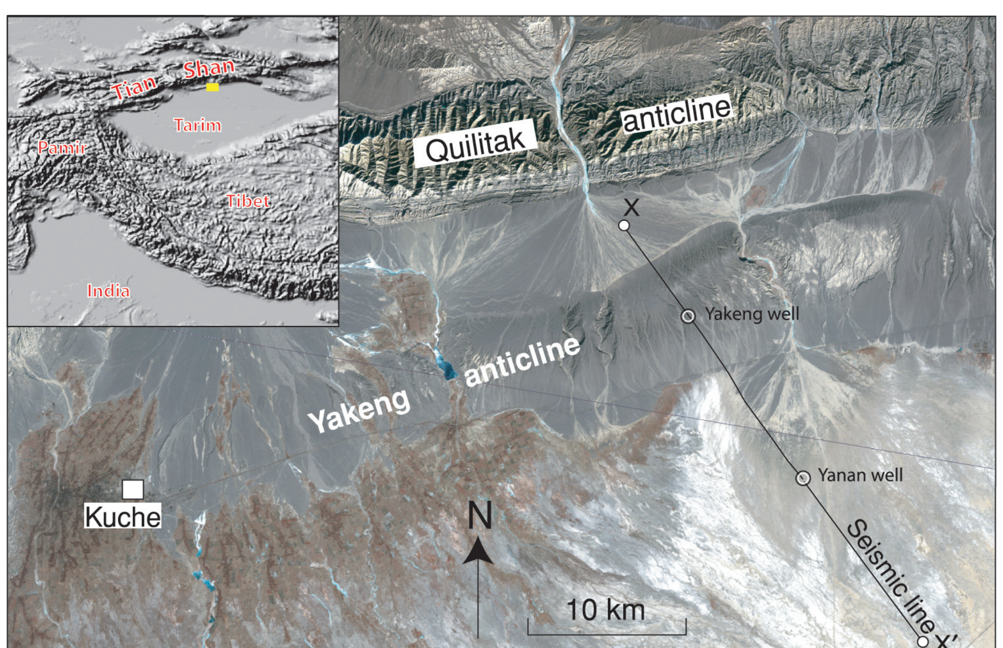

Figure 1: *Yakeng fold at the front of the southern Tianshan. (Landsat TM)*

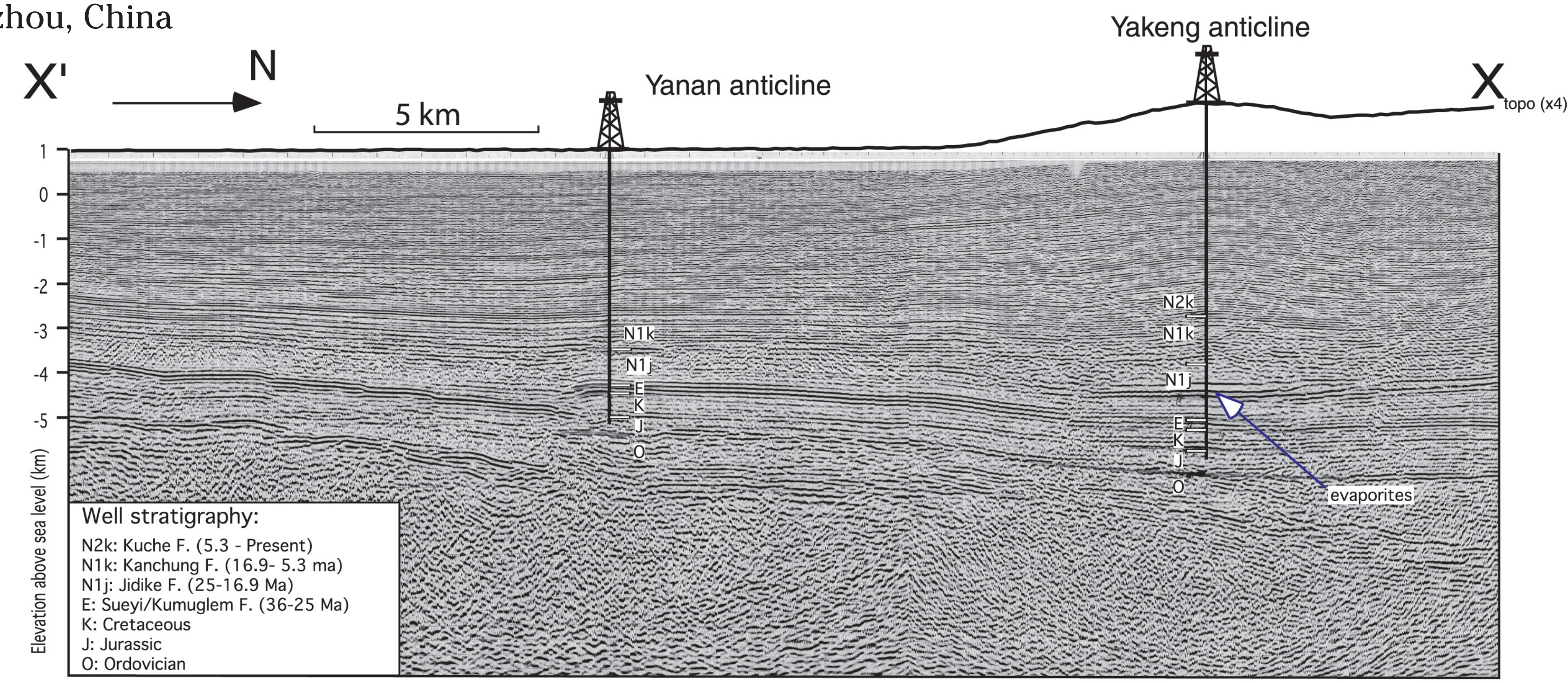

Figure 2a: *Uninterpreted seismic (horizontal scale equals vertical scale, topography exaggerated x4).*

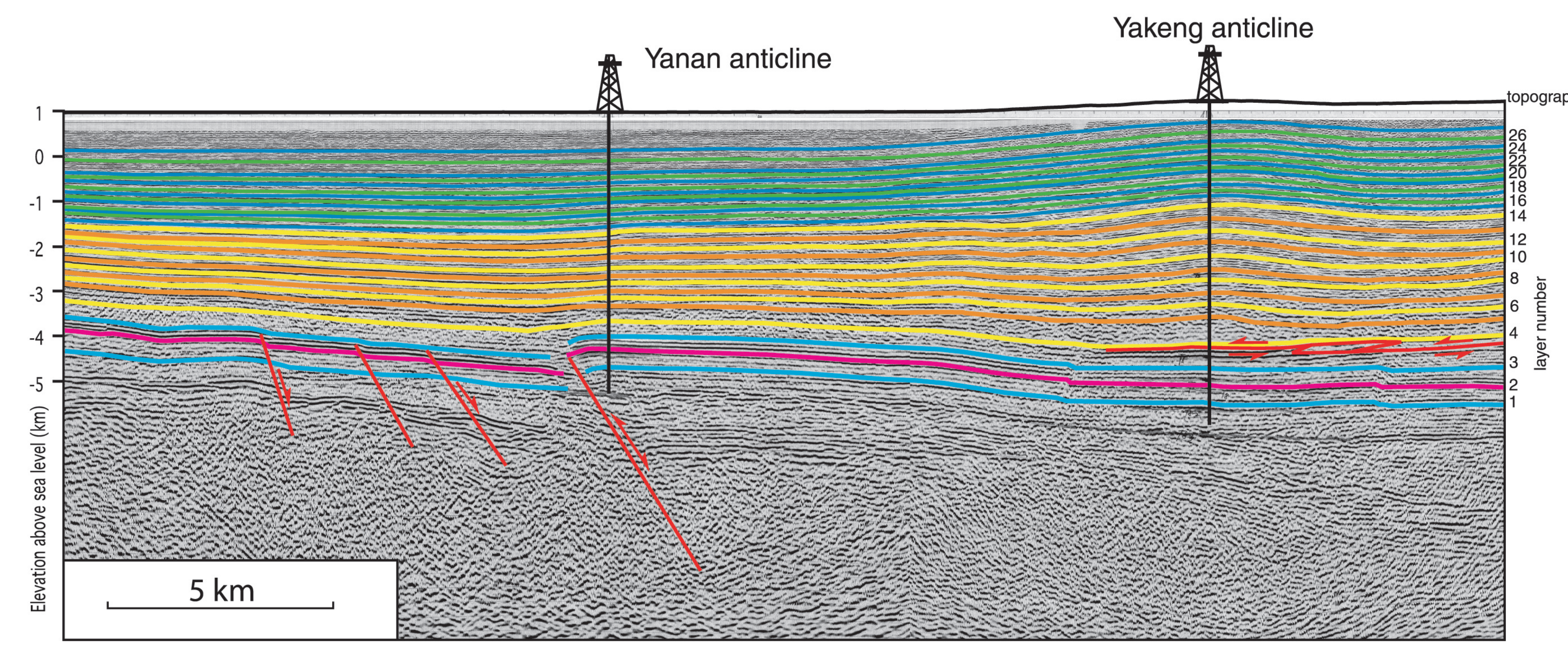

Figure 2b: *Interpreted seismic (horizontal scale equals vertical scale, including topography) showing the 27 horizons used in analysis of Yakeng. Two major detachments bound the thickening yellow and orange interval.*

2-14: Surface expression of fold growth and sediment trapping

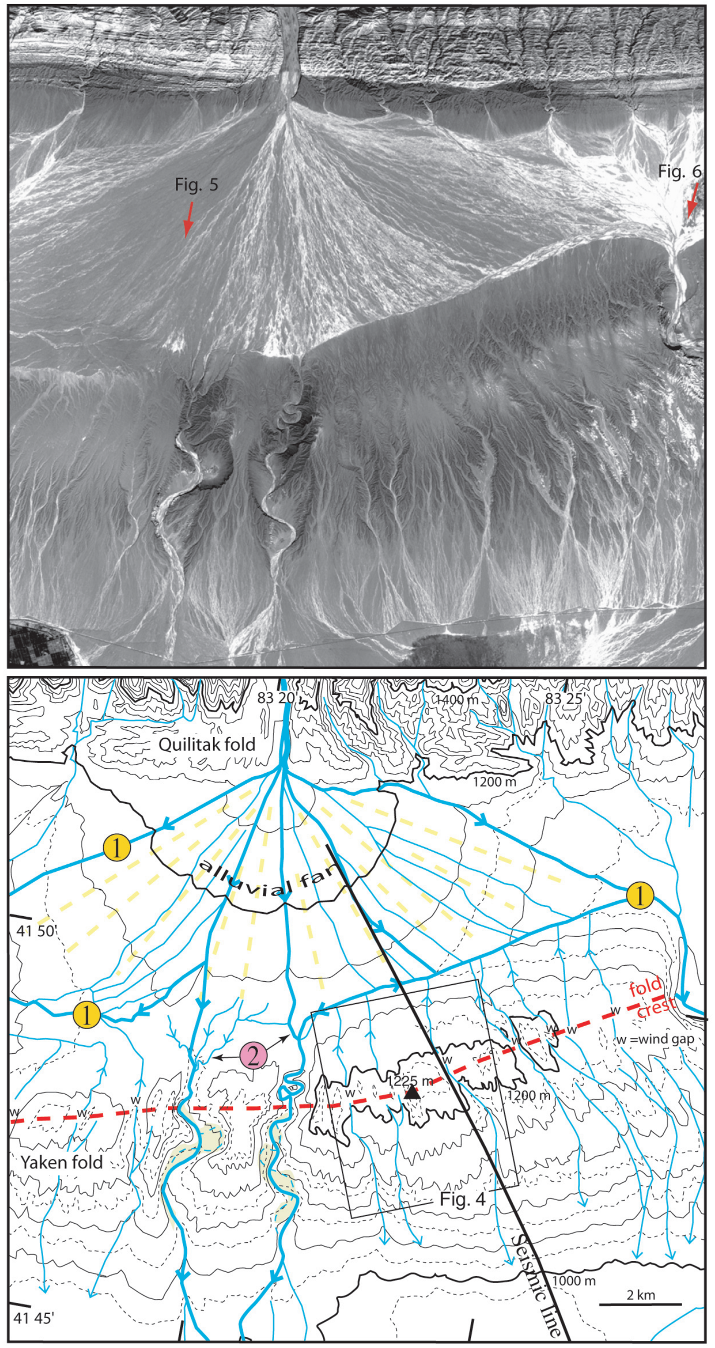

Figure 3: *The active Yakeng anticline forms a 6-km-wide rounded topographic ridge that few rivers can incise, as shown by the many wind gaps (w). Northward tilting of the north flank of Yakeng and alluvial deposition both decrease stream gradients, which favors the development of channels on the sides of the alluvial fans and along the northern limb of Yakeng (1). Others channels have a converging pattern (2) which increases their stream power sufficiently to keep incising Yakeng anticline. The increase of meander amplitude and wavelength across Yakeng also reflect these changes in gradient.*

Geomorphic expression: The morphology of the 50–150-m-high topographic anticline illuminates the most recent increment of fold growth and sedimentation. It is a deformed and incised alluvial surface for which prior through-going drainage systems are still visible (Figures 3 and 4), showing that deposition previously exceeded uplift, similar to the present situation at Kuche where Yakeng is largely buried (Figure 1). Limb dips (3–4°) in the valley east of the seismic line (Figures 1, 2b) are a significant fraction of the seismic dips (4–6°), indicating the extreme youth of Yakeng anticline.

Drainage and sedimentation: The topographic anticline is a barrier to the river networks (Figures 1, 3); only regionally important rivers can now cross Yakeng. Smaller streams previously crossed Yakeng anticline as demonstrated by the numerous well preserved wind gaps (Figure 3) and by southward merging channel networks that are continuous across the wind gaps (Figures 3, 4). This implied reorganization of drainage networks is an effect of decreasing stream power caused by decreasing stream gradients associated with fold growth. As a result, sediment is preferentially trapped north and south of Yakeng (Figures 5, 6), producing a topographic expression that is narrower than the anticline at depth, especially on the north flank (Figures 2, 3, and 12).

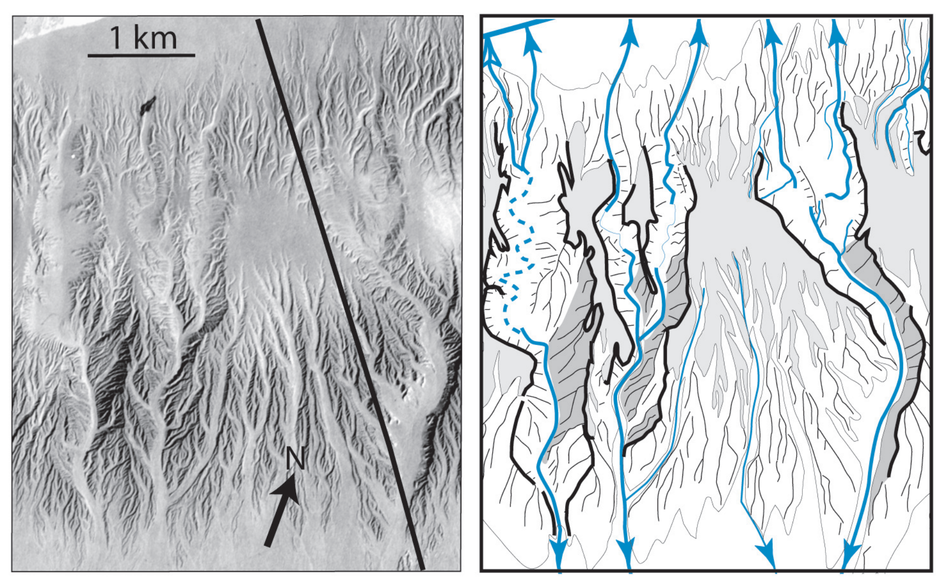

Figure 4: *Southward-converging drainage networks are interrupted by wind gaps at the crest of Yakeng anticline. Flow is now to the north on the north flank of Yakeng. These southward converging networks formed before Yakeng anticline developed its present topographic expression. Seismic line in black.*

Figure 5: *Low rounded morphology of the Yakeng anticline.*

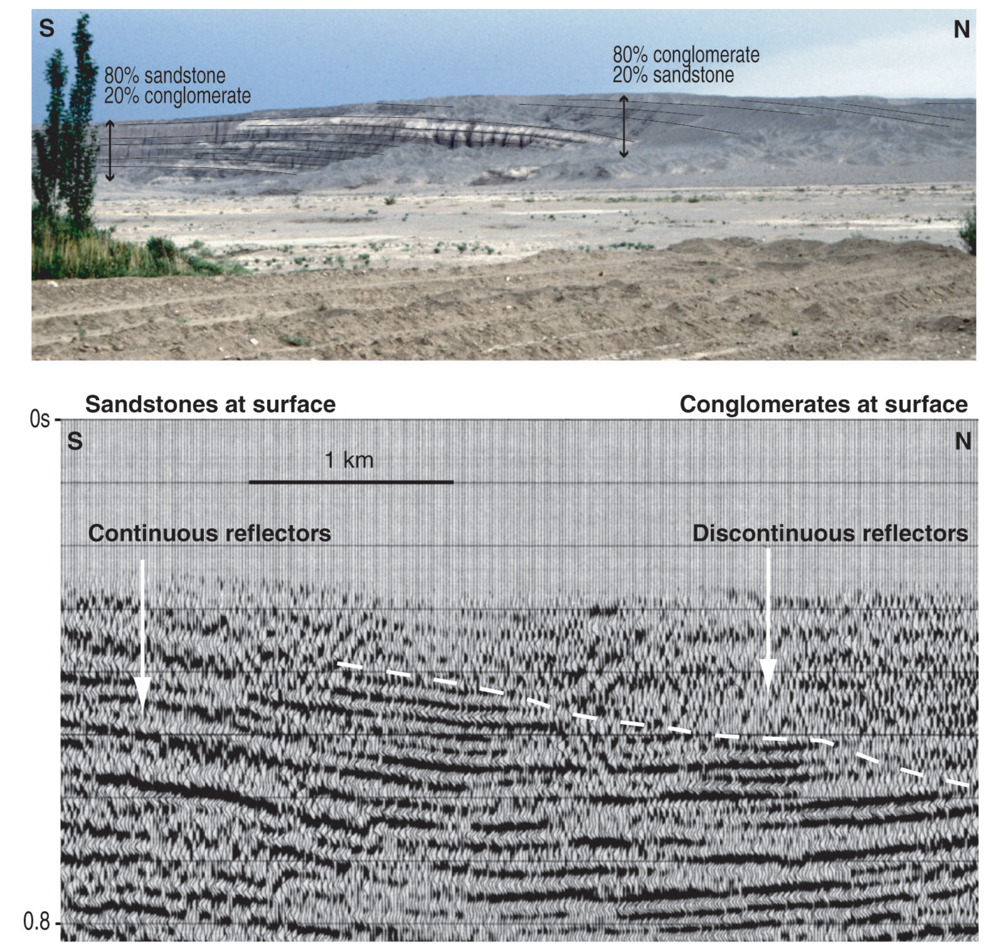

Figure 6: *A facies change on the northern limb of Yakeng anticline is visible in the field (top) and in the seismic reflection profile (bottom). The northern edge of the anticline is mainly formed by thick dark conglomerate (Xiyu F.) whereas its top is composed mainly of yellow-grey sandstone. Most coarse dark conglomerates began to be deposited during the glacial period (1.8 Ma to present). They progressively filled the basin between Quilitak and Yakeng anticlines.*

2-14: Seismic characteristics and folding mechanism

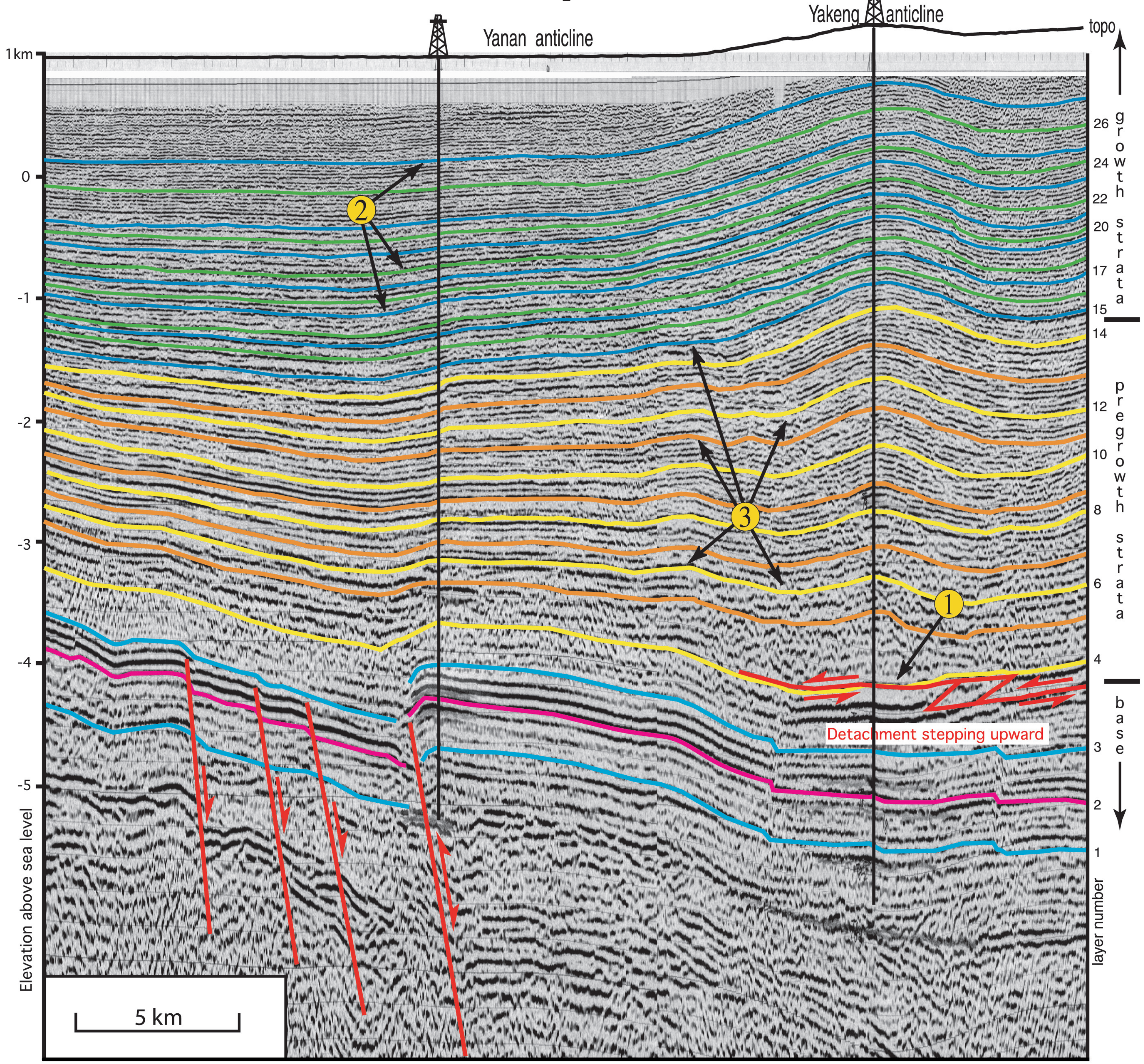

Figure 7: Yakeng anticline dies out downward in height and width, indicating a basal detachment (1, horizon 4), which extends to the north under Quilitak anticline. Yanan anticline is a basement-involved inversion structure that is young, as shown by changes in structural relief on its south flank (2). Yanan interferes with Yakeng anticline (3), making analysis of Yakeng more challenging.

Initial assessment: Yakeng anticline dies out downward (Figure 7), suggesting it is a classic detachment fold that can be analyzed quantitatively for shortening and timing (Figure 8). However Yakeng is too complex because of regional variation in stratigraphic thickness below horizon 15 (Figure 9) and interference with Yanan anticline (Figure 7). This forces us to move our analysis of Yakeng from the *depth domain* to the *thickness domain* (Figures 10–14).

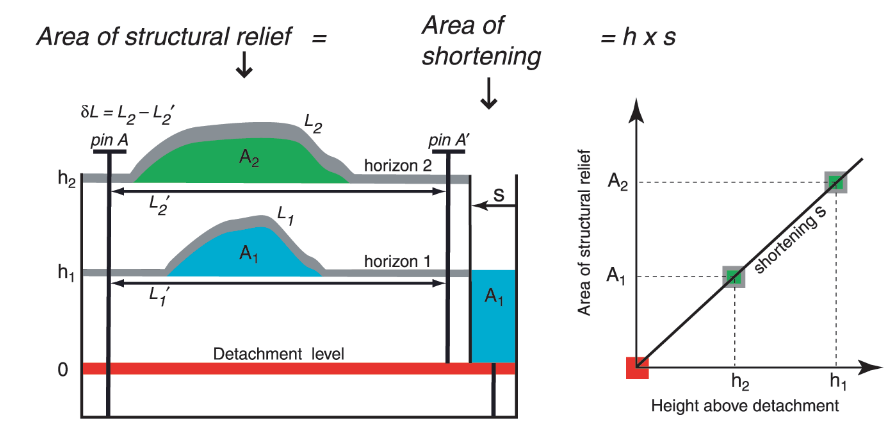

Figure 8: Classical detachment folds are characterized by a linear upward increase of area of structural relief A = hs *within pregrowth strata (Epard and Groshong, 1993). By measuring the area of structural relief of many horizons the magnitude — and the timing — of shortening can be determined* s = A/h. *Shortening can also be determined for each layer from bed-length measurements* $s = \delta_L = L_2 - L_2'$*, but only if bed length is conserved. Yakeng anticline is significantly more complex than this model.*

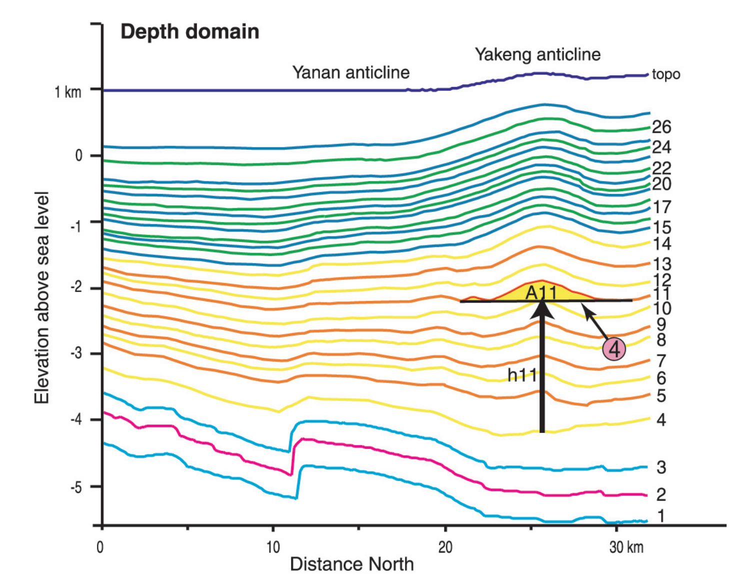

Figure 9: Measurement of area of structural relief (A11) *following the model of Figure 8 is ambiguous since the undeformed regional gradient (4) is hard to determine because the basement is folded and thickness varies regionally. Therefore we move our analysis to the thickness domain (Figures 10–14).*

2-14: Analysis of Yakeng in the thickness domain

By flattening the structure to appropriate horizons we can view the structure in the thickness domain and more easily determine the regional stratigraphic gradients (Figures 10–12), which are needed to measure areas of structural relief (Figures 10, 12). The analysis shows us that interval 4-15 has undergone significant shortening (1200 m) and interval 4-5 has undergone additional diapiric flow (0.8 km^2). The overlying strata (15-27) show modest thinning over Yakeng and nearly constant thickness relief, which can be modeled as the beginning of growth. Strata above horizon 27 are more strongly thinned, showing a recent acceleration of growth of Yakeng, preceeding its emergence as a topographic feature.

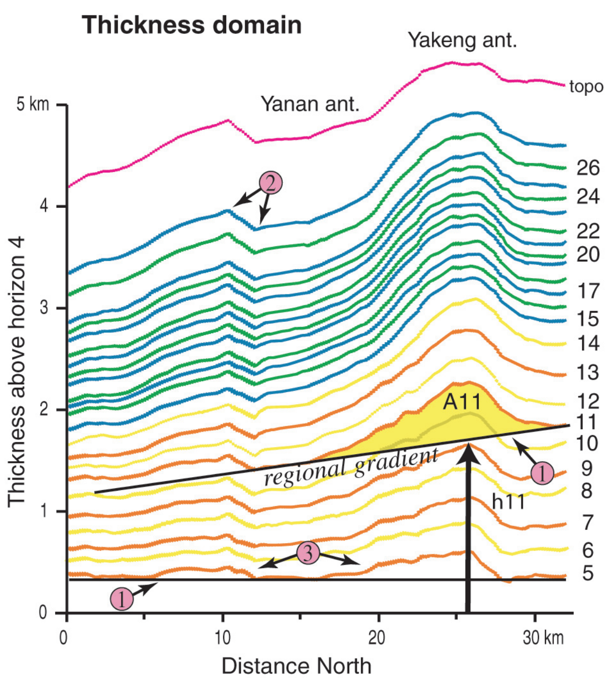

Figure 10: *Section produced by flattening on horizon 4. It is easier in this* thickness display *than in the* depth display *(Figure 9) to identify the regional stratigraphic gradients (1,* also see *Figure 11) for measuring area of structural relief* (A11) *and undeformed height* (h11). *Note that Yanan anticline largely disappears in this thickness display because it is a flexural-slip fold conserving layer thickness, whereas Yakeng is visible because it has grown by layer thickening. Yanan anticline appears only as a depression (2) because of stratigraphic thinning due to growth (see interval 15–22 Figure 11), but at deeper levels (3) the slight depression is produced by flow of the basal evaporitic layer (4-5).*

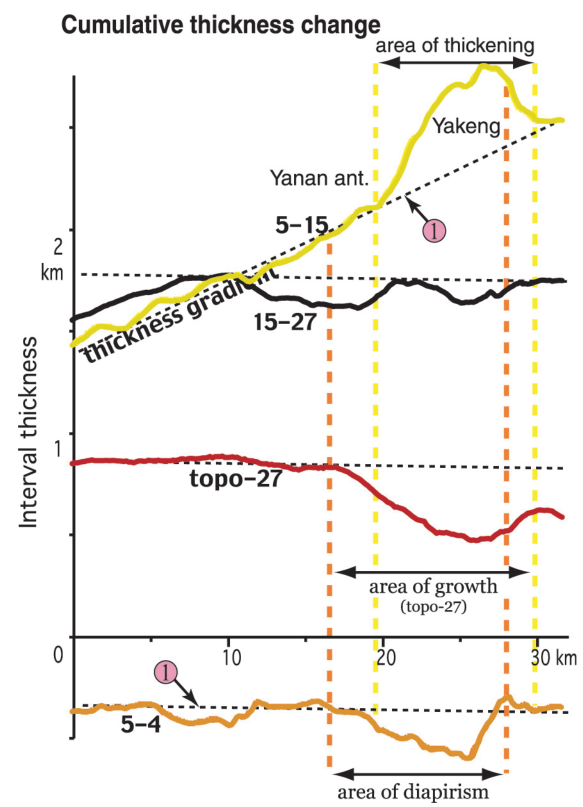

Figure 11: *The keys to interpreting Yakeng anticline are revealed by its thickness variations. The basal evaporitic interval (5–4) shows thickness variation largely caused by diapiric flow (Figure 13). Interval 5-15 shows large regional northward stratigraphic thickening reflecting syndepositional flexure of the basement, plus local structural thickening at Yakeng. The overlying interval 15-27 shows stratigraphic thinning over both Yanan and Yakeng anticlines, indicating growth. The uppermost interval (topo-27) shows large thinning over Yakeng, indicating accelerated growth including diapirism.*

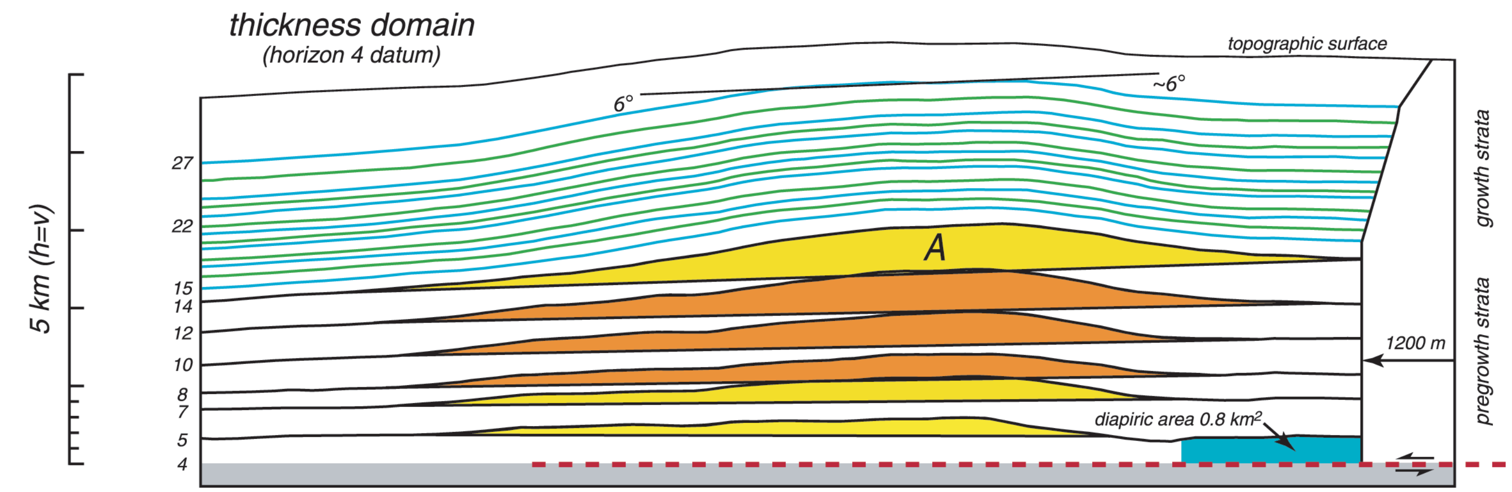

Figure 12: *Yakeng anticline flattened to horizon 4 (h=v). The analysis given below shows that horizons 5–14 have undergone 1200 m of shortening and thickening above an evaporitic detachment. There is and additional 0.8 km^2 of diapirism in the basal layer (4-5). Horizons 15–27 show a nearly linear upward dearease in shortening. After horizon 27 time shortening and uplift has accelerated leading to topographic emergence.*

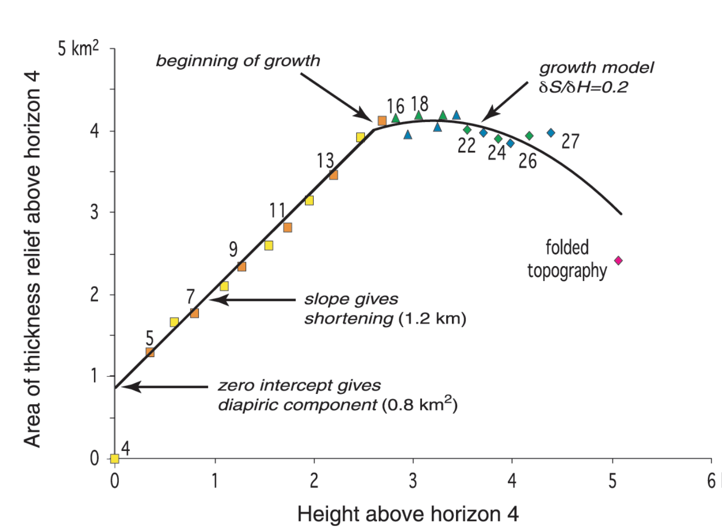

Figure 13: *Area of thickness relief increases linearly from layer 5 to 15 indicating a nearly constant shortening of 1200 m (compare Figure 8). The nonzero intercept indicates an additional 0.8 km^2 of diapiric flow in the basal evaporitic interval (4-5). The interval of nearly constant relief (15–27) can be modeled as a growth internal (δS/δH = 0.2, assuming diapirism is after horizon 27.)*

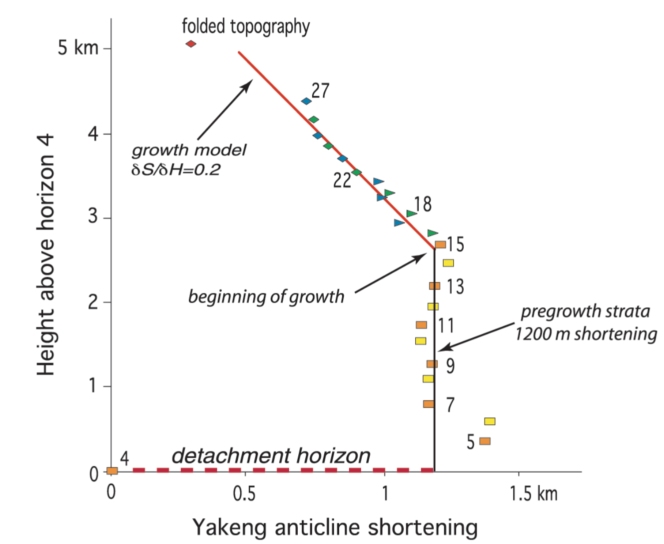

Figure 14: *Shortening is calculated from area of relief minus the diapiric area (see Figures 8 and 13). The nearly linear shortening within the growth interval (15-27) suggests that diapirism is late, leading to the topographic emergence of Yakeng. The larger apparent shortening of layers 5-6 may suggest a small additional diapiric component.*

Conclusions: Yakeng anticline the value of analysis in the *thickness domain:*

- Thickness analysis clearly identifies the growth, pregrowth, and diapiric intervals.
- Beds in the pregrowth sequence have shortened by 1200 m.
- There a significant diapiric component in the basal evaporitic layer (0.8 km^2).
- The growth of Yakeng between horizons 15–27 shows a nearly linear rate of shortening, followed by an acceleration of growth and topographic emergence.
- The topography shows folding of previously through-flowing stream valleys

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