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Geological evidence for changes in the propagation directions of slip increments on growing normal faults

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The growth and accumulation of displacement on faults can be studied from two perspectives: slip distributions on active faults over short timescales and finite fault displacements derived from geological studies. A key objective is to combine these perspectives to understand how individual fault slip increments relate to long term fault growth, but this is challenging since it is difficult or impossible to define the slip increments that occurred during the formation of ancient faults. In this paper we present the results of outcrop studies that relate the propagation direction of fault slip increments, derived from field observation, to the displacement accumulation on faults.
Determination of the propagation direction of fault slip increments is possible in the Kardia lignite mine in the Ptolemais basin of northern Greece due to an unusual circumstance in which normal faulting is synchronous with distributed bedding parallel slip. Bed-parallel slip surfaces intermittently offset the Quaternary faults as they grew to form discontinuities on otherwise continuous fault surfaces. Subsequent fault slip increments bypassed these discontinuities to re-establish a continuous fault trace and leave an associated ‘dead’ splay. The geometry and displacement distributions at these fault/bed-parallel slip intersections record the fault displacement at the time of bed-parallel slip and whether the next fault slip increment had an upwards or downwards component to its local propagation vector.
A database (N = 88) of slip propagation directions and fault throws was derived from continuous mapping of mine faces during lignite extraction over an eight year period. The data demonstrate a clear relationship between slip propagation direction and the accumulation of fault displacement on individual faults. During the early stages of fault growth, slip events propagated almost exclusively upwards through the mined sequence, but later stages of growth are marked by slip events showing both upward and downward components of propagation demonstrating that the location of the point of initiation of fault slip events varied over the fault surfaces as the faults grew. Initial upward propagation is consistent with an overall upward propagation of the fault system from depth towards the contemporaneous free surface. The transition from upward to mixed propagation directions occurs later in the growth history of larger faults which can be attributed to their larger surface areas and extent below the mine level increasing the likelihood that slip events will initiate at depth rather than close to or above the mining level. Early establishment of a hierarchy of fault sizes and surface areas at low throws suggests that fault growth subscribes to a constant length model.