Visualization of Angular Unconformities and Tectonic Angular Discordance Measurement Constraints by Structural Geometrical Flattening: Case Studies in the Permian (California), Grand Canyon (Arizona), Chad Basin (Nigeria), Algarve Basin (Iberian Peninsula), and the Aegean Sea Basin (Turkey)

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ABSTRACT

Geometrical flattening of stratigraphic data (seismic data, outcrop data, and interpreted well sections) is often practiced within a sequence stratigraphic framework with an emphasis on the chronostratigraphic order of sequence tracts. The representation of geological data within a chronostratigraphic framework reveals significant features such as non-depositional or erosional features (unconformities and condensed sections) that may not be obvious in the original domain. Angular unconformities represent time-significant surfaces formed when an older rock unit is tilted and truncated and a younger rock unit is deposited on top of it; they present a noteworthy situation where the older rock unit may be composed of several sequence tracts, simultaneously separated from the younger rock unit by a common time-significant interface. This implies that chronostratigraphic interpretation can be applied across this interface by geometrically flattening the rock units. We apply geometrical flattening using newly developed software: WheelerLab. We examine case studies in the Permian Strata (California), the Grand Canyon (Arizona), the Chad Basin (Nigeria), the Algarve Basin (Iberian Peninsula), and the Aegean Sea Basin (Turkey). Results show that the angular unconformities are represented as angular shaped hiatuses in the chronostratigraphic section containing an acute angle less than or equal to the total tectonic angular rotation (sum of angular discordance and dip angle).

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- Geometrical flattening of stratigraphic data (seismic data, outcrop data and interpreted well sections) is often practiced within a sequence stratigraphic framework with an emphasis on the chronostratigraphic order of sequence tracts
- Angular unconformities represent time-significant surfaces formed when an older rock unit is tilted and truncated and a younger rock unit is deposited on top of it.
- Angular unconformities present a noteworthy situation where the older rock unit may be composed of several sequence tracts, simultaneously separated from the younger rock unit by a common time-significant interface.
- This implies that chronostratigraphic interpretation can be applied across this interface by geometrically flattening the rock units.
- We apply geometrical flattening using newly developed software: WheelerLab.

- Section of the Tarpeats sandstone over the Nankoweap Formation.
- The Tapeats sandstone consists of an upper slope forming transition zone of nearly equal distribution of brown sandstone and green siltstone and shale of Bright Angel Shale lithology and a lower unit of cliff forming sandstone and conglomeritic sandstone (Billingsley and Hampton, 2000).
- The angular discordance of the unconformity is approximately equal to the dip of the upper part of the Unkar Group given that above the unconformity the base of the tarpeats sand is approximately flat.
- Application of the bed restoration process reveals the angular unconformity as an angular shaped hiatus with an upper acute angle of approximately 12 degrees, which is equal to the dip of the upper part of the Unkar Group

- An angular unconformity resulting from late Permian tectonism can be observed between the lower Permian Strata and Upper Permian to Triassic Strata in between the Owens valley and Death valley in east-central California.
- Restored bedding altitudes indicate Darwin Canyon Formation made up the gently dipping east flank of a north trending structural high that formed before the Triassic was deposited (Stone and Stevens, 1988). The restored Permian strata has an angular discordance of ~16 degrees with the restored Triassic strata. In addition the overlying Triassic strata has a dip angle of approximately 15 degrees.
- Figure 2 shows the orientation of the tilted layers as well as the orientation of the restored bedding after flattening. The angular unconformity appears as an acute angle of ~33 degrees. This value is equal to the sum of the post-depositional dip of the Triassic strata with the angular discordance between the Permian strata and the Triassic strata.

A basin-wide angular unconformity exists between the Tertiary sediments and underlying faulted and folded Cretaceous sediments of the Chad basin, in Northern Nigeria. Avbovbo et al. (1986) classify the Chad basin as a rift-related basin affected by folding in the subbasin.

- This seismic example covers a much larger area than the outcrops in the other examples; hence the part of the fold can be observed.
- Avbovbo et al. (1986) also identify seven sequences based on characteristic reflection patterns. The third, fourth and fifth sequences are tectonically folded and truncated by the sixth sequence .
- To a first order approximation, the fifth sequence has a dip angle of approximately 13 degrees.
- The restored bedding reveals the upper part of the unconformity is angular shaped hiatus with an acute angle approximately equal to the dip angle.
- The lower part of the unconformity preserves the geometrical curvature of the third and fourth sequences in the temporal domain.

- The Angular unconformity of the Aegean Sea basin occurs between tilted and folded early cretaceous to early-Paleogene scaglia facies and flat lying Eocene sediments above, and is exposed on road between Adapazari and Bilecik, Turkey (Doglioni et al, 2002; See Figure 4).
- The angular unconformity in Algarve basin occurs between dipping upper Triassic sandstone and folded Moscovian turbidites and is exposed at the Telheiro beach, Portugal (Pereira et al., 2017).
- The sections of both angular unconformities are fairly similar in geometry.
- The angular unconformity of the Algarve basin has an angular discordance ~73 degrees while the angular unconformity of the Aegean Sea basin has an angular discordance of ~60 degrees.
- The chronostratigraphic section generated by flattening depict the angular unconformities as angular shaped hiatuses with acute angles equal to ~73 degrees and ~60 degrees respectively.

- Results reveal that the angular unconformities are represented as angular shaped hiatuses in the temporal rock record containing an acute angle approximately equal to the sum of angular discordance, which defines the unconformity with the dip angle of the overlying layers.
- In cases where there is very little tectonic rotation after deposition of the overlying layer, the acute angle is approximately equal to the dip angle of the underlying layers.
- For other work and Software see: Amosu and Sun 2017 (a-f), Amosu and Wehner (2015), Amosu et al, (2016), Amosu (2013), Amosu and Smalley (2014), Amosu et al, (2011,2012, 2013), Attanayake et al (2010).

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