Fault and Fracture Detection in Unconventional Reservoirs: A Utica Shale Study*

Hesham Refayee[1], Steve Adcock[1], Hardeep Jaglan[1], Nanne Hemstra[1], and Kristoffer Rimaila[1]

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Abstract

Without a good understanding of the faults and fractures present in a net pay zone, the possibility of wasting valuable resources is high. We characterize here fractures and faults within the Utica Shale by integrating routinely used methods, such as geometric attributes (Dip filter, Similarity, Fault enhanced similarity) and comparing them with a new fault attribute that extracts faults and fractures, and improves their visibility. The new method also helps minimize random noise in the seismic data. In order to fully optimize faults and structures, we first filtered the seismic data with a structurally oriented filter to reduce the noise and improve the imaging quality. Using a single attribute to derive information from faults and fractures is not optimum; therefore, we employed a second step, applying several conventional attributes, such as similarity, curvature, and fault enhanced filters. These successfully identified the fault and fracture geometries. A comparatively new fault attribute, known as Fault likelihood and defined as a power of semblance, was then used to capture and delineate faults and fractures in the same Utica Shale area. This attribute is created by scanning a range of fault dips to identify maximum likelihood. The value range of the fault likelihood attribute is between 0 and 1. In order to obtain even sharper fault planes, a filtering step is also performed. When compared to traditional attributes, the faults and fractures are better defined by the new method. In addition, the new fault likelihood attribute is extremely versatile and can be used to characterize fault and fracture proximity and density.

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Objectives

- Detect faults and fractures in an unconventional play (Utica Shale) and refine these features by applying different types of attributes.
- Highlight the importance of using more than one attribute

Presenter's notes: One attribute is not optimum to visualize features of interest, but a combination of them would increase the reliability of the observed features. Faults and fractures in the study area, of different character, have different characteristics.

Highlight the importance of using more than one attribute (unconventional attributes) in order to examine the network of fractures and locate sweet spots for drilling. Fractures are good in this area, some other areas are to be avoided, for fractured zones leak hydrocarbons, e.g., Barnett Shale in Texas.

Overview

- Geological Background
- Data Conditioning
  - Dip Extraction
  - Structurally Oriented Filter
- Conventional Attributes
  - Similarity
  - Polar Dip
  - Curvature
- Unconventional Attributes
  - Thinned Fault Likelihood
  - Fracture Density & Proximity
- Conclusions

Presenter's notes: Conditioning the data--to make it ready for attribute computation
Results of applying some conventional attributes (attributes been used since mid 90s) on an unconventional reservoir
New attributes--to help us understand better the locality of the faults and the fracture network distribution.

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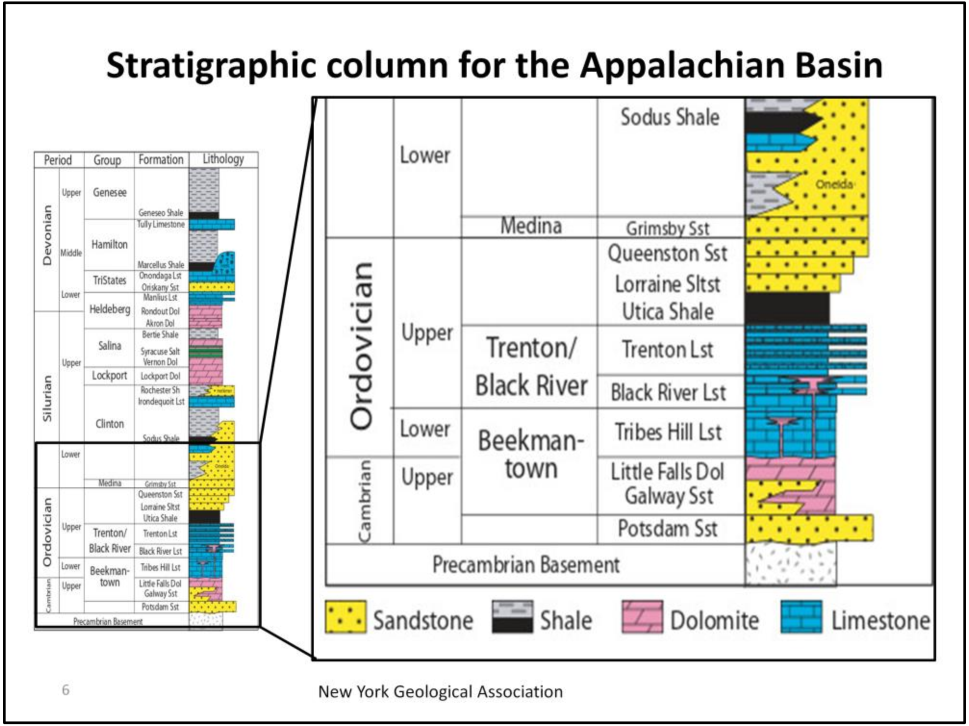
Background

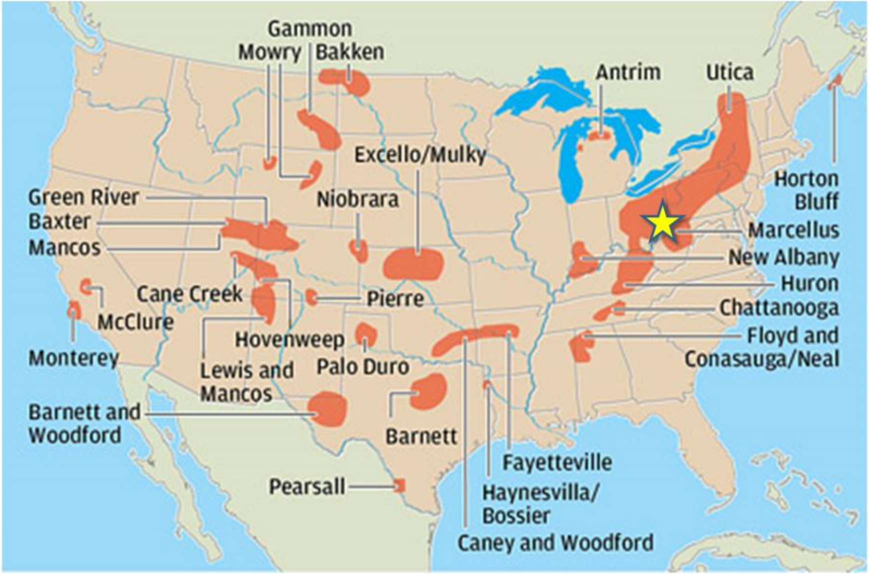
- One of the most important unconventional plays in US
- Thickness on average of about 150 ft.
- Both a source rock and reservoir, contains significant amounts of oil and gas.
- Late Ordovician age, approximately 2000 ft. below the Marcellus shale, separated by the Silurian succession
- Natural fracturing important for enhancing productivity

Presenter’s notes: Utica is one of the most important unconventional plays in US.
Organic-rich calcareous shale with interbedded limestone.
Range from about 100 – 500 ft., thickening toward SE. Low organic content but thickness makes it economical.
The Utica shale is a source rock and reservoir, contains large amounts of oil and gas. Underlying Point Pleasant Formation is also target.



Presenter's notes: Sandstones (Clinton and the older Rose Run) are conventional reservoirs with the Utica and Point Pleasant shale formations charging the Clinton. Utica is seal for Trenton-Black River.

Utica Shale



Presenter's notes: NW-SE maximum stress, compression. Yet normal, reverse faults and wrenching.

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Seismic Data Conditioning

- This procedure is aimed at:
  - Dip & azimuth volume was computed
  - Clean-up the data from incoherent noise
  - Enhance the lateral continuity of seismic events while sharpening the fault scarps

Seismic Data Conditioning

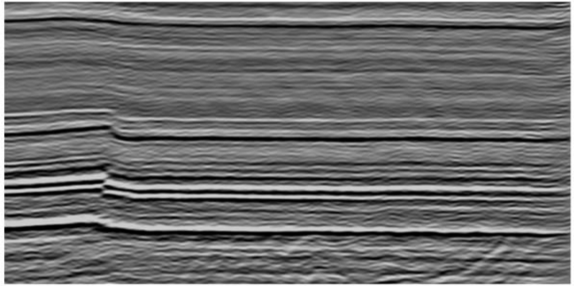
- The primary use of the dip & azimuth volume is to generate high-resolution geometrical attributes
- A highly filtered dip & azimuth volume was used to smooth the data from incoherent noise
- Filtering the noise along the geological structure using median statistics.

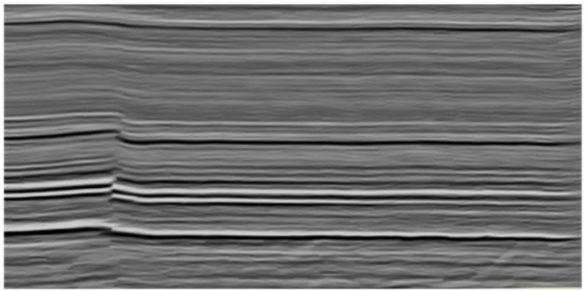
Seismic Data Conditioning

- A second filter, called dip-steered diffusion filter (DSDF), was defined to reserve and improve the fault definition

- The DSDF replaces bad quality seismic traces at a fault location with good quality traces from the neighboring traces, resulting in sharpened fault scarps

Seismic Data Conditioning





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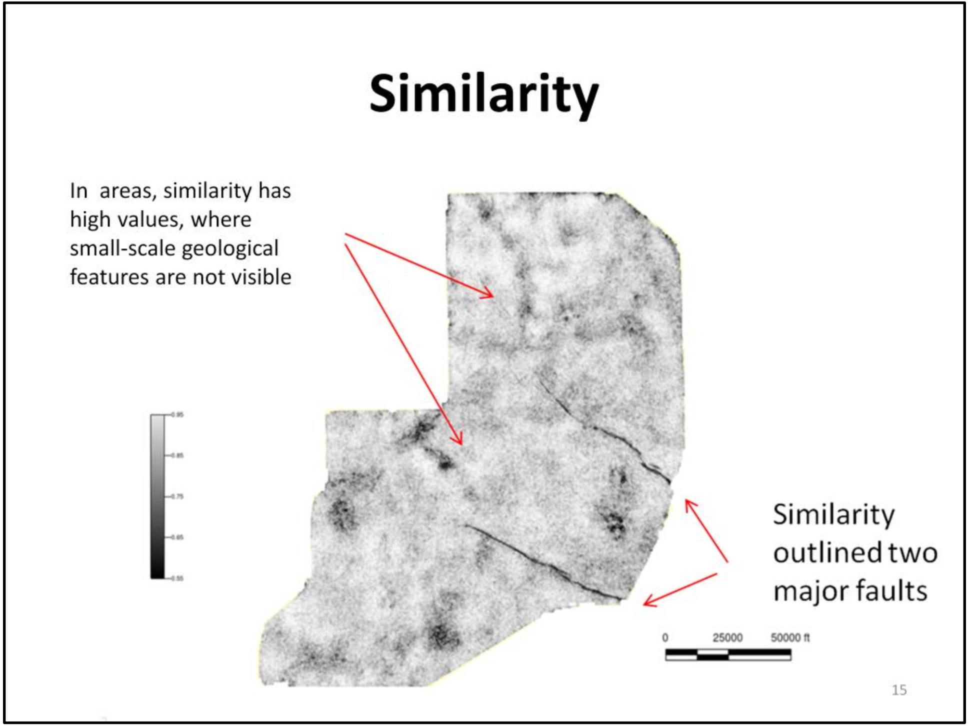
Presenter's notes: Top of Utica Shale was used to produce attribute maps.

Conventional Attributes-Similarity/Coherency

- Similarity Attribute: is typically applied for fast delineation of geological discontinuities such as large scale faults and stratigraphic features.



Presenter’s notes: Buckling, not faulting. Thus similarity high. Nature of faults is two fold: major faults in NW-SE direction are reactivated, but other are younger.
A similarity value of close to 1 means two trace segments are almost identical, whereas a similarity of less than 0.6 or 0.5 suggests discontinuities between the two trace segments.
Major faults are identified, however, similarity did not provide any other structural detail at the top of Utica.

Conventional Attributes – Polar Dip

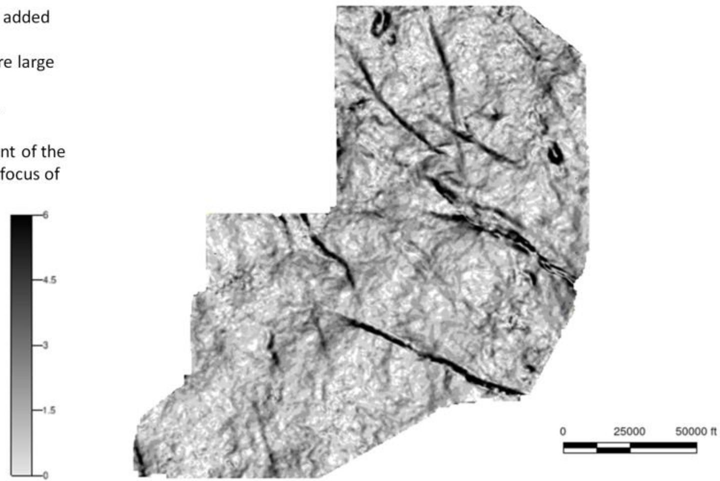
- The polar dip attribute combines the dip in inline and cross-line directions from the dip & azimuth values, to generate true geological dip

- The polar dip attribute was applied to visualize the seismic reflector dips. It helps in identification of faults as they typically have higher dip values

Polar Dip

- Polar dip attribute added more value to the interpretation, where large and small faults are conspicuously seen.

- Better enhancement of the fault edges and the focus of the faults

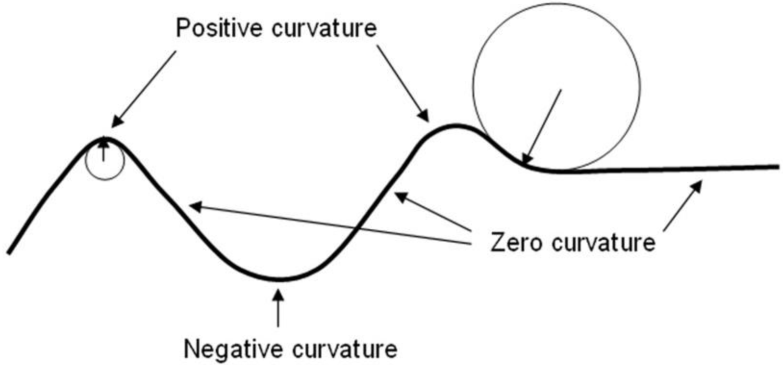


Presenter's notes: Major faults (NW-SE) are better imaged Other faults with almost N-S orientation, are nearly intersects with major faults; shows evidence of a shear component, stress regime that did not show up on the similarity attribute.

Curvature

- Curvature attribute measures the curvedness of a mapped surface.
  - Different types of curvature attributes are frequently used to delineate faults and fractures.
- Our computation of curvature is guided by the a detailed dip & azimuth volume containing high resolution dip information, which results in better definition of the structural features.

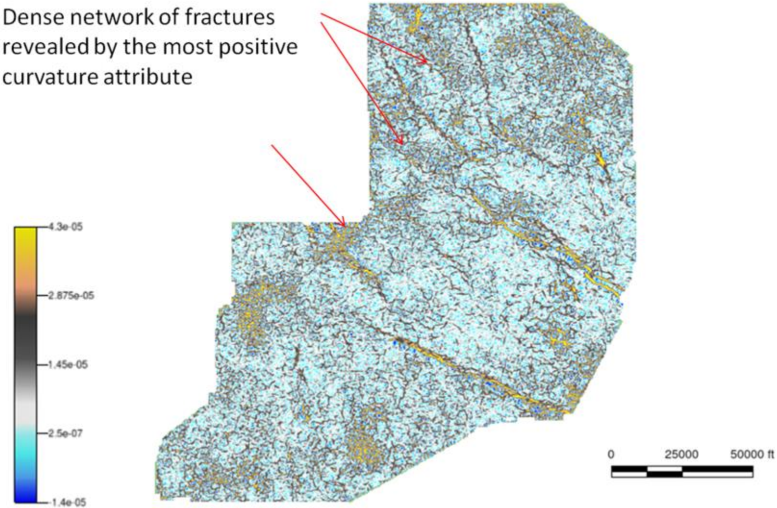
Curvature



Chopra and Marfurt (2007)

Most Positive Curvature

Dense network of fractures revealed by the most positive curvature attribute

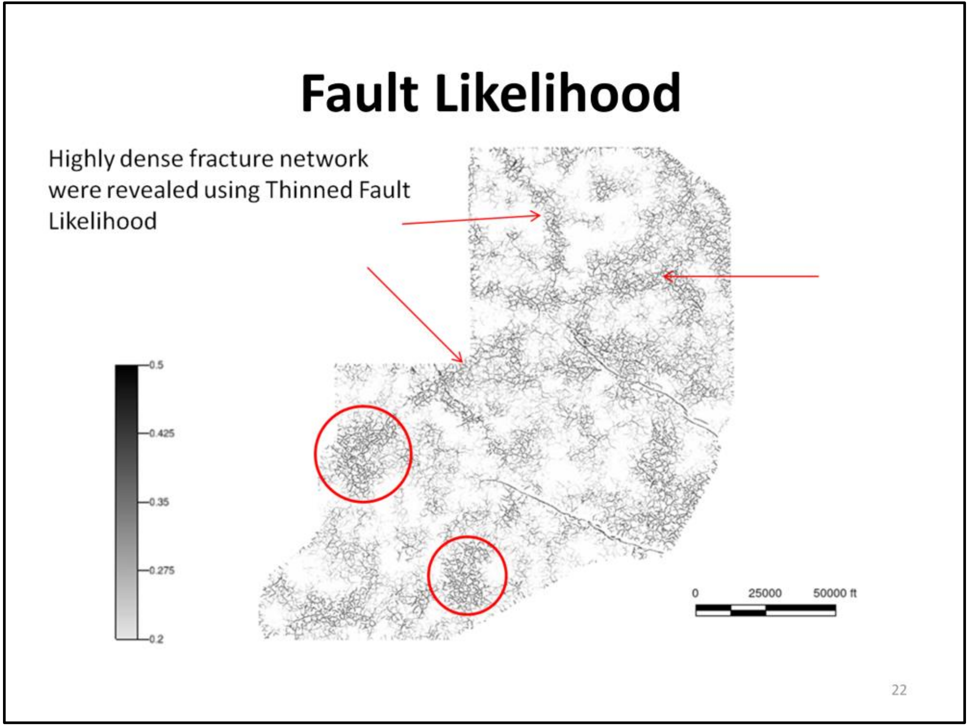


Presenter's notes: Application of the most positive curvature attribute at this level does reveal a dense network of fractures. Apart from the main NW-SE faults, finer detail is also provided by the most positive curvature in areas where similarity and polar dip attributes are rather featureless.

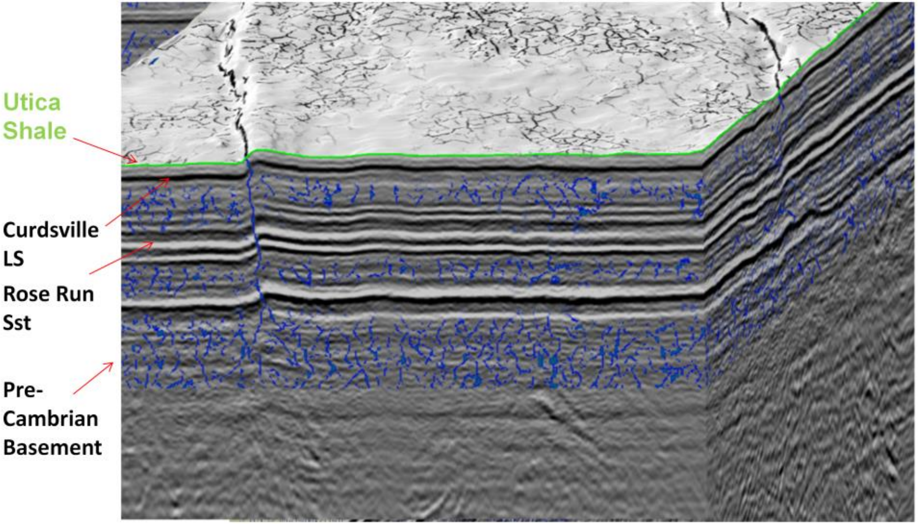
Fault Likelihood

- Fault Likelihood is used to capture faults and fractures. It is defined as the power of semblance; it is computed based on a given range of dips and strike
- This attribute is created by scanning a range of fault dips to identify maximum likelihood of discontinuity. The value range of the fault likelihood attribute is between 0 and 1.

Wu and Hale (2014)



Presenter's notes: Fault likelihood provided the best definition of fault geometries in 3D and also nicely delineated the fracture networks..



Chair display shows the major fault intersections with the top Utica shale reservoir.

Presenter's notes: Buckling, not sharp faults. Dewatering of shales, no fractures in Rose Run Sandstone, nor in Curdsvile Lime stone.

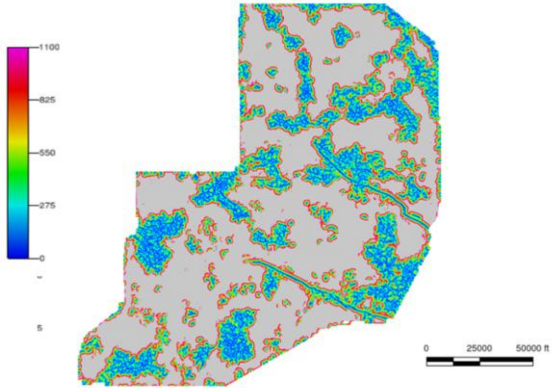
Fracture Proximity

- Fracture proximity attribute is useful in visualizing the connectivity of fracture networks.
- It measures lateral distance from a trace position, classified as a fracture based on a threshold applied on the input fault likelihood attribute.
- It reveals how close a particular sample is from a fracture, as well as how close fractures are to each other, and it improves the visibility of the fractures and their network.

Fracture Proximity

This attribute shows the proximity of fractures.

The color bar depicts the distance in feet to the nearest fracture anomaly



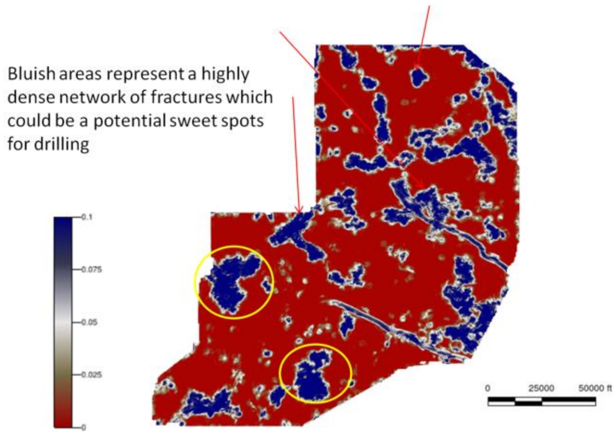
Fracture Density

- Fracture Density highlights the location of concentrated fractures within a user-defined radius. Consequently, this attribute directly identifies regions with higher fracture density as sweet spots for hydrocarbon extraction.
- Furthermore, it is useful in designing a good artificial fracturing plan which takes into account the complexities that arise from interaction between the induced fractures with the natural ones.

Fracture Density

- Fracture density depicts the fracture density at the top of Utica reservoir.

- Red colored areas are the ones with less number of fractures per square mile; whereas the blue-colored blobs represent the areas of high fracture density, essentially the potential sweet-spots for drilling



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Conclusions

- Conventional geometrical attributes such as similarity, polar dip, were able to outline major faults but did not capture de-watering faulting in the Utica shale
- The Curvature attribute was partially successful in bringing out the fine detail about the fracture networks.
- The Fault Likelihood attribute provided the best definition of fault geometries in 3D, and also delineation of the fracture networks.

Presenter's notes: Different character of different types of faults; thus different attributes.

Conclusions

- Fracture density helps to identify areas with dense networks of naturally occurring fractures. These areas are potential sweet-spots for drilling.

Presenter's notes: The fault attribute volume was used as input in the fracture density attribute.

Acknowledgements

We are grateful to TGS for providing the data and giving the permission to present this work.

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Thank you for your time

Q&A