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Appalachian Basin Geophysical Symposium, June 2, 2021

GEOPHYSICAL SOCIETY OF
PITTSBURGH

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Maximizing Value from Investment in Geophysics: Expensive Luxury or Cheap Insurance? *Nancy House*, Integrated Geophysical Interpretations Inc., LLC*

3D seismic imaging revolutionized hydrocarbon exploration providing a robust picture of the subsurface. Higher prices enabled expensive technologies and investments in the development of previously uneconomic deposits. The balance between development and the market value of the gas or oil is critical. Recent advances in 3D seismic allow interpreters to map areas of higher productivity and identify bypassed reserves and with machine learning applied to quality 3D seismic data integrated with completion and production data can optimize spacing, high grade productivity and even predict potential reserves.

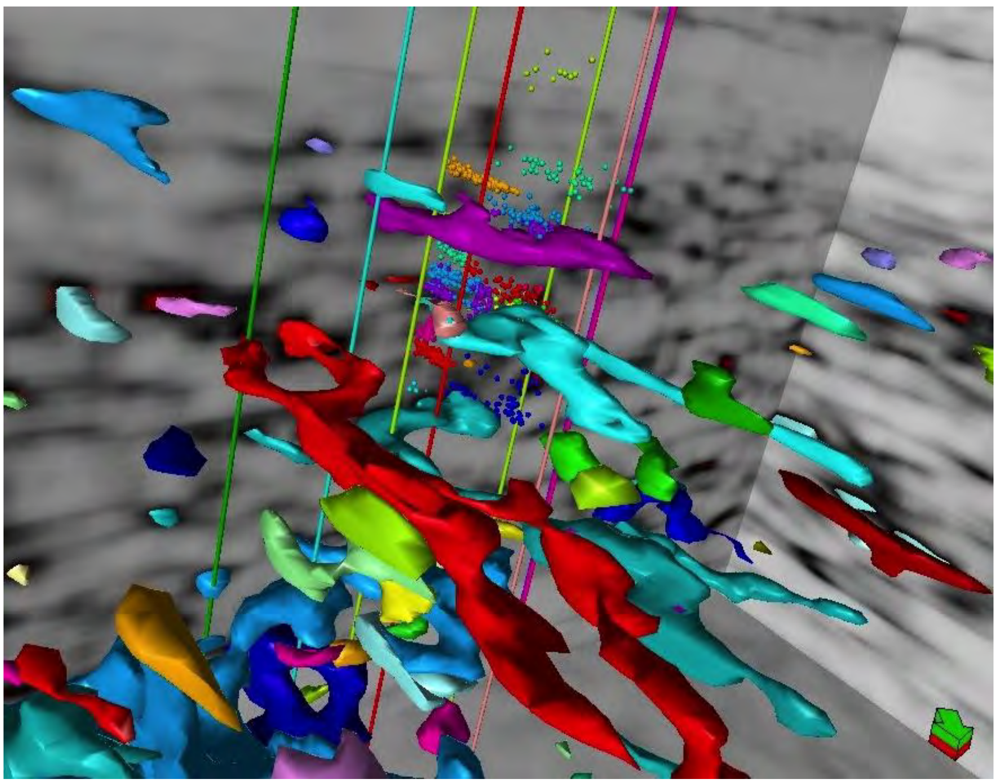

Figure 1 . Seismic Variance attribute with geobodies extracted along equal variance points from 3D seismic volume. Wells with Microsiesmic locations illustrate the correlation between even clusters and apparent fluvial channels.

Decision makers at small and large oil and gas companies often view 3D seismic and geophysical investments as a luxury that can be forgone when budgets need to be cut. However, describing the improved outcomes in economic terms and can justify the investment and improve the overall economics of a play. A case is presented where 1/6 wells need to be sidetracked at a cost of $500,000 each due to unseen geologic complexity. When determining the value of having a clear seismic image before drilling it is reasonable to apply these statistics based on the number of wells to be drilled in an area. Additionally, the value of a resource is calculated by normalized production or expected reserves per 1000' of effective lateral length. This can be improved by having a clear image ahead of the drill bit. These values can be evaluated through use of decision analysis to provide an economic value of a project with and without an investment in 3D seismic or other data before making the decision.

The balance between development and the market value of the gas or oil is critical. Through economic analysis incorporating the cost of geophysical information the long-term benefits of the of the investment. We propose a simple method to evaluate the investment in seismic using simple decision analysis coupled with expressing the cost in ways that are applicable to the full economic benefit of the data.

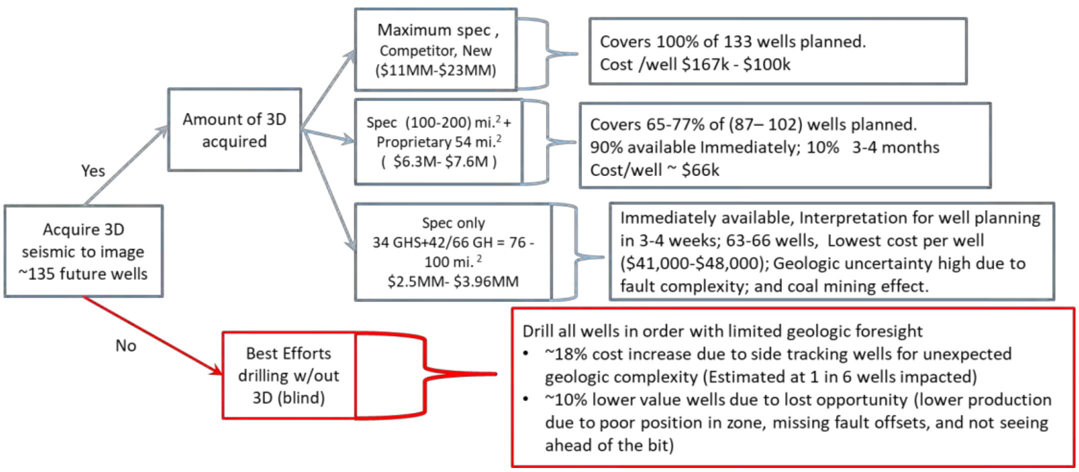

Figure 2 Decision to invest in differing quantities of 3D coverage with different timing and cost associated. Her the best decision was to immediately license enough data to provide 3D coverage for half of the planned wells.

Nancy House

Nancy House, a member of SEG for over 40 years, joining in 1978 as a graduate student at CSM, has worked as a geophysicist for multinational corporations and small independent oil companies primarily as an interpreter on and offshore US, South America and Africa (West and East), and other areas. She is second-generation geoscientist, growing up in South America and Singapore. She has a BA in Geology/Geophysics from the University of Wyoming, (1976), an MSc in Geophysics from Colorado School of Mines (1979), and did additional postgraduate work at Colorado School of Mines in Reservoir Characterization, Economics and Geophysics (2000-2002).

Nancy has served on numerous committees including, Global Affairs Committee, Women's Network Committee, Finance Committee, Membership Committees in SEG. She served as Denver Geophysical Society President/Past President from 2008-2010, General Chairman for SEG AM 2010, and Secretary - Treasurer 2011-2012, Chairman of SEG Women's Network Committee 2012-2013, and the Finance Committee 2012-2014. She has been a regular contributor to TLE, presenter at meetings (Best Poster 1995), a reviewer for Geophysics and a session chair for various meetings. She also served on several task forces to understand critical business issues around SEGs global activities. She has been a member of AAPG, Dallas GS, Den GS, RMAG, DEG (Division Environmental Geology of AAPG), AGU, AWG, and EAEG.

As SEG President 2017-2018 she focused on increasing diversity and inclusion in the profession of geophysics and continue strategies implemented by Rd. Bradford and Bill Abriel, to recognize the social contribution of Geophysics and applied geophysics in areas such as pollution mitigation, groundwater location and mineral exploration. As the industry evolves with the gradual replacement of oil and gas by renewables, she hopes to expose the critical application of geophysics to effective and efficient production of minerals needed for renewable energy resources

Optimization of Unconventional reservoirs Using Fiber Optic Distributed Sensing. *J. Andreas Chavarria* and Todd Brown OptaSence*

Analysis of fracture networks and their associated SRV in unconventional reservoirs has increasingly being conducted with fiber optic and Distributed Acoustic Sensing (DAS). This is done by measuring the temperature, strain and microseismic signals within the reservoir by fiber optic cables deployed in the wells. Permanent and intervention fibers have been used for strain/ms analysis. In this presentation we show how these combined datasets from fiber optic systems can constitute an efficient and cost-effective tool to understand the fracturing processes in the reservoir. More importantly we show how real-time high-resolution completions surveillance with distributed sensing can impact the efficiency of treatment programs.

Strain and microseismic fiber measurements reveal that we can monitor fracture opening/closure and its associated microseismicity. The low frequency DAS responds to the fracture creation within the treatment zone and has the high resolution needed to illuminate specific aspects of the completion design in real time. The microseismic response on the other hand includes activity away from the stage zone and is likely related to pore pressure and stress conditions in the surrounding rocks. The joint analysis of the strain and microseismic data from the fiber optic system reveals that the stress shadow delineated by the strain front can provide the framework for understanding microseismic events generated within it.

Dual strain and microseismic measurements from fiber present a low-cost opportunity to not only illuminate the completion zone but also understand it's geomechanics. The availability of DAS measurements opens the door for more accurate estimations of SRV and overall assessments of the treatment zone. It further provides operators an efficient tool for real time assessment of their well treatment.

J. Andreas Chavarria

Andres Chavarria is OptaSense's Oilfield Services Technical Director. He has more than 20 years' experience in the area of borehole seismic. His current focus is the use of distributed sensing fiber optic data for engineering and geoscience applications.

He has a background on borehole seismology (MS and VSP) and was previously the Geophysical Processing Manager at OptaSense, SR2020 and Paulsson. He has conducted work in other areas of geophysics including geothermal, mining and groundwater. He holds an Engineering Degree on Geophysics from the National University of Mexico and a PhD Degree on Geophysics from Duke University.

Fracture Type Identification for Real-Time Pumping Parameters Optimization to Maximize Hydraulic Fracturing Surface Area for Production. *Thomas Johnson* ShearFRAC*

Unconventional reservoirs are filled with extensive micro-fractures created by hydrocarbon expulsion that are reactivated when hydraulic fracturing. Unlike fracturing more conventional rock that is reliant on highly conductive tensile fractures, these micro-fractures fail in shear and greatly increase the connected surface area to nanodarcy unconventional rock. By actively increasing the number of shear fractures created during hydraulic fracturing, operators can re-enter these micro-fractures and maximize the well's productivity. This talk will present modern physics based on hydraulic fracturing and proppant placement coupled with the field use of real-time software capable of measuring and quantifying tensile & shearing fractures on a second-by-second basis and how operators made "on-the-fly" changes to their pumping schedule to maximize shear fracturing. Case histories will be presented showing the real-time changes and added production benefits of shear fracturing.

Thomas Johnston, President & CEO at ShearFRAC™

Tom started thinking about how unconventional rocks fail in high school and went on to gain an MS Geology from Penn State University, focusing on geomechanics and reservoir engineering. Tom honed his passion for unconventional reservoir development at Noble Energy in the Marcellus, Eagle Ford, and Permian Basins. His last position at Noble Energy was as a development and operations geologist before joining ShearFRAC™.

Seismic + neural network + wells + (some science) = pore pressure.

Marianne Rauch, TGS, Mike Perz, TGS*

The overpressure in unconventional on-shore basins is complicated by complex geology, low permeability and the presence of TOC in the shale reservoirs. The pressure can change laterally over short distances and these variations are very difficult to predict using well data only. This presentation shows the results of a pore-pressure prediction study using seismic, pressure and well data in the Wolfcamp Formation, Delaware Basin.

Seismic inputs for such a study are 3D estimated volumes of the elastic seismic attributes Vp and density. Both data types are derived from elastic pre-stack inversions, a process which requires careful, amplitude-preserved seismic processing. The pore-pressure model was constructed using direct pressure information from drilling such as Diagnostic Fracture Initiation Tests (DFIT), Drill-Stem Tests (DST), mud weight and all other information that indicates pressure changes. A cross-plot of the pressure values (expressed in terms of vertical effective stress) and well-log measured velocities allows a regression based on the Bower's equation effectively linking Vp to pore pressure. By applying the same regression relationship to the seismic-based Vp volume, the actual pressure can be estimated away from the wells at all points in x, y, z.

Also discussed is the use of neural networks to estimate missing sonic logs. Essential inputs are drilling and well information which can be sparse. Often, drilling info is available but no sonic log was recorded. A novel approach using neural networks was applied to predict sonic logs at well locations that have logs like GR, resistivity and caliper for example. Using those predicted sonic logs allows for a more accurate estimation of the Bower's variables.

A calibration of the seismic pore-pressure values with production information and gas readings shows a high degree of certainty. The method should be applicable in the tight rock environment in all on-shore basins and should yield similar results.

Marrianne Rauch

Marianne received her PhD in Physics in 1985 from Uni Graz in Austria. She started her oil career as research assistant at Curtin University in Perth, Australia more than30 years ago and has been active in geophysics ever since then. Marianne lived in many places and worked on-shore and off-shore basins all over the world. Her main specialties are DHI, seismic processing, depth migration, potential fields and researching new technologies, methodologies. She likes to do applied research, mentor and teach and is a seasoned presenter at conventions and workshop. In 2020 she received the Special Commendation Award from the SEG. She has published a good number of articles on several subjects and still is passionate about geoscience and the thrill to get more and unique information out of geophysical measurements that help drilling more successful wells. Currently, she is the Principal Technical Advisor, TGS, Houston.

The Converted-P Mode: Valuable, already in Your Possession, Not Utilized. *Bob A. Hardage Key Note Speaker*

The dominate type of seismic reflection data that has been acquired across onshore prospect areas is data that are generated by P-wave sources and recorded with vertical geophones. This term, “P source” encompasses vertical vibrators, vertical impacts, and buried shot-hole explosives. These sources, together with vertical-geophone receivers, have been used to create P-P images for decades.

However, there are two images, not just one image, embedded in data generated by a P source and recorded by vertical geophones. Image #1 is the P-P image. P-P data involve a down-going P ray path and an up-going P ray path and thus are a “direct-P” mode. Image #2 is an SV-P image. Because an SV-P reflection involves a down-going SV ray path and an up-going P ray path, SV-P data are a “converted-P” mode.

This presentation will explain the physics of the converted-P mode, will illustrate that P sources are also amazing S-wave sources that generate effective illuminating SV wavefields, and will show converted-P images created in numerous basins. All converted-P images that will be shown have been extracted from legacy “P-wave” data that were recorded several years in the past. Thus, hundreds-of-1000s of sq. km. of converted-P data are already recorded. Seismic users simply have to extract “P-wave” data from digital storage in order to create SV-P images.

SV-P data generate the same image, and provide the same fast-S/slow-S behavior, as do P-SV data. Because P-SV data are the most common S-wave mode that is used by reflection seismologists, the equivalence between SV-P and P-SV data means that S-wave reflection seismology can be practiced with P sources and vertical geophones. This low-cost, already available, access to S-wave images, S-wave information, and S-wave applications needs to be utilized.

Bob A. Hardage Key Note Speaker

Bob A. Hardage received a PhD in physics from Oklahoma State University. His thesis work focused on high-velocity micro-meteoroid impact on space vehicles, which required trips to Goddard Space Flight Center to do finite-difference modeling on dedicated computers. Upon completing his university studies, he worked at Phillips Petroleum Company for 23 years and was Exploration Manager for Asia and Latin America when he left Phillips. He moved to WesternAtlas and worked 3 years as Vice President of Geophysical Development and Marketing. He then established a multicomponent seismic research laboratory at the Bureau of Economic Geology and served The University of Texas at Austin as a Senior Research Scientist for 28 years. He has published books on VSP, cross-well profiling, seismic stratigraphy, and multicomponent seismic technology. He was the first person to serve 6 years on the Board of Directors of the Society of Exploration Geophysicists (SEG). His Board service was as SEG Editor (2 years), followed by 1-year terms as First VP, President Elect, President, and Past President. SEG has awarded him a Special Commendation, Life Membership, and Honorary Membership. He wrote the AAPG Explorer column on geophysics for 6 years. AAPG honored him with a Distinguished Service award for promoting geophysics among the geological community.

Machine Learning Techniques for Prediction of Brittleness from Geophysical Logs and Seismic Signal in an Unconventional Reservoir.

Tobi Ore, and Dengliang Gao, Department of Geology and Geography - West Virginia University*

Brittleness, related to the stored energy in the rock before failure, is known to be an important reservoir property in hydraulic fracturing. In particular, under a certain level of differential stress, brittle rocks fail creating planes of weakness that are kept open by the injected proppant, causing secondary permeability in the rock. This reservoir property is usually estimated from cores and well log data, providing estimates around the borehole not to mention the cost of acquiring the data. It is, therefore, imperative to develop a workflow that can cost effectively predict the brittleness for wells without the right suite of logs and spatially away from the well location. Here we report the utilization of a robust, data-driven workflow to predict brittleness from conventional geophysical logs and seismic signal.

We estimate brittleness using 6 different techniques that utilize mineralogy and elastic logs and analyzed the data to test for difference between the estimation techniques by fitting an Analysis of Variance model, blocking by stratigraphic units. With a 5% significance level, the data suggested that there is insufficient evidence of a difference between the 6 brittleness estimation techniques, and we adopted the elastic logs template. Using gamma ray, density and neutron logs as predictors, the gradient boosting outperformed the support vector regressor and artificial neural network in predicting the brittleness at the well location with a training and testing R2 score of 0.95 and 0.85 respectively. This emphasizes that neural networks are not a panacea of all modeling problems, and other algorithms should be explored before accepting the results.

We demonstrate that using a seismic texture-based data-driven inversion has a promising future for brittleness forecast spatially which can serve as an input for reservoir modeling. Also, the algorithm offers a workaround to the paucity of wells with relevant geophysical logs by vertically sampling and calibrating the seismic response to the log responses. Such a workaround can apply to horizontal wells given its dense lateral sampling along the reservoir. The workflow used to execute the prediction of brittleness from the seismic data can be extended to predict other reservoir properties, such as porosity, that has a physical or sensible relationship with seismic amplitude responses.

Tobi Ore

Tobi Ore is a Geology Ph.D. student at West Virginia University where he is conducting research in the areas of seismic interpretation, reservoir characterization, and machine learning. He graduated from the University of Lagos, Nigeria with a bachelor's degree in geophysics. Particularly, he is interested in quantifying implicit biases associated with applying machine learning techniques in geophysics and creating more robust applications having practical implications. He has presented his research papers at various regional and international conferences. He is a recipient of numerous merit-based scholarships such as, the Society of Exploration Geophysicists scholarship and the Geophysical Society of Pittsburgh Scholarship. He is an active member of SEG, EAGE, SPE, NABG, and AAPG.

Understanding the Pressure Regimes in the Lower Tertiary Wilcox in the GoM, *Jakob Heller* Ikon Science Americas*

In this presentation we will discuss the importance of, and challenges to pore pressure prediction in the GOM. The presentation will discuss the key findings of a regional Lower Tertiary geopressure study conducted in the GoM and how understanding the regional pressure distribution may help in reducing uncertainties locally.

More specifically we will discuss and identify the Wilcox regional pressure regime and its role in controlling key aspects of the petroleum system. The presentation will discuss reservoir compartmentalization vs connectivity and its implications for drilling/exploration. We will also provide an improved understanding of the fracture and overburden pressures including an understanding of the controls on overpressure generation, i.e. overpressure mechanisms, including analysis of temperature regimes close to salt. Finally, the presentation will highlight how this study and its findings may aid identifying new exploration opportunities in the GoM.

Jakob Heller,

Jakob has a MSc in geology from the University of Copenhagen, Denmark. His Master's thesis was undertaken in collaboration with Eqiunor Norway and the Technical University of Denmark (DTU) and focused on the sedimentology and diagenesis of the Middle Jurassic Garn formation, offshore Mid-Norway. In the last 15 years Jakob have worked as a geologist/pore pressure specialist working in Denmark, UK, Egypt and Malaysia. The work includes the following topics; regional pressure studies, well planning, pore pressure prediction from seismic velocities, hydrodynamics, column heights and seal breach studies. Jakob has been the main technical lead on more than 120 project studies globally in areas such as NW Shelf/onshore Australia, Kutai Basin and East Java Indonesia, NW Borneo (offshore Sarawak, Brunei and Sabah), Gulf of Thailand/Malay Basin, Cuu Long, Nam Con Son, Phu Khan basins offshore Vietnam, offshore Japan, China and offshore/onshore Pakistan. Jakob has also worked in the Gulf of Mexico, the Permian and onshore Alaska. Jakob has presented at numerous technical conferences.

Adventures in Drilling Chapter 13: Overcoming seismic pitfalls while horizontally developing the Marcellus in the Alleghany Structural Front.

M. Evelyn Hudson - Inflection Energy LLC*

The Alleghany Structural Front, part of the Appalachian Structural Front, constitutes the transition area between the Valley and Ridge province to the Appalachian Plateau province in Pennsylvania (Figure 1). The Valley and Ridge consists of folds and thrusts of ~12000ft of Cambrian thru Silurian sediments, while the structure of the Appalachian Plateau generally consists of Upper Silurian Salina salt-cored anticlines with up to 2500ft of vertical relief. Thrust faulting in the Valley and Ridge has décollements in the Cambrian Waynesboro shale and the Ordovician Reedsville shale (Figure 2), which climb up section to the Salina salt décollement in the Appalachian Plateau.

Along the structural front in Lycoming County, PA, the Middle Devonian Marcellus Shale is between 250ft and 300ft thick. It is comprised of an Upper Marcellus black shale (Oatka Creek Member), a thin Cherry Valley Limestone, and a Lower Marcellus black shale (Union Springs member) that transitions to the Lower to Middle Devonian Onondaga Limestone at its base. The lateral drill target is the top of the basal Lower Marcellus, a subunit with a high organic content. With the structural complexity of the area determined by at least two stages of movement during the Alleghanian Orogeny, drilling in - and staying in - the target window is challenging. At the time of Inflection's entry into the play, no 3D seismic had been proposed in the area. The first - Seitel's South Muncy 3D - was shot in 2011. Subsequent programs allowed Inflection to acquire 142mi2 in three speculative and two proprietary infill surveys.

The depth to the top of the Marcellus over Inflection's acreage position ranges from ~3000ft to 9500ft TVD and has pressure gradients of up to .85 psi /ft. From south to north, the formation drops progressively deeper in discrete blocks bracketed by high angle sealing faults. Within those discrete blocks are small relief kink-folds that are interpreted as the decapitated tops of pre-existing folds from an earlier stage of movement during the Alleghanian Orogeny. All structural features have to be navigated during drilling and accounted for during completion.

Due to the structure in the AOI, pad sites are usually placed near large faults with vertical offsets of 1200ft to 2000ft to maximize lateral length. Wells have been drilled with lateral inclinations of up to 26°up-and-down and have crossed faults with 150ft of throw. The greatest seismic interpretation challenges encountered are lateral velocity changes and ray path distortions due to variable topography, overhanging thrust sheets, and variable stratigraphic thicknesses. These challenges affect conversion to depth and lateral positioning of faults and anticlinal crests. All acquired seismic volumes have been merged into one PSTM data volume which is used to construct well plans. PSDM has been attempted but failed to converge on an accurate enough depth image. Inflection's solution has been the implementation of a novel method of depth conversion.

However, despite the area's challenges, the rewards are great. For example, the best well to date with a lateral in Marcellus shale for 5193ft had an initial production (on choke) that averaged 15mmcfgpd for the first year of production and, as of the end of 2019, has had a cumulative production of >15 BCF. In 2019, Inflection successfully implemented pad drilling operations around this lateral using an extensive reservoir field study to mitigate the effects of such a long producing parent on successive child wells. With this success, Inflection plans to continue pad drilling operations, continuing to boldly go where no one has gone before.

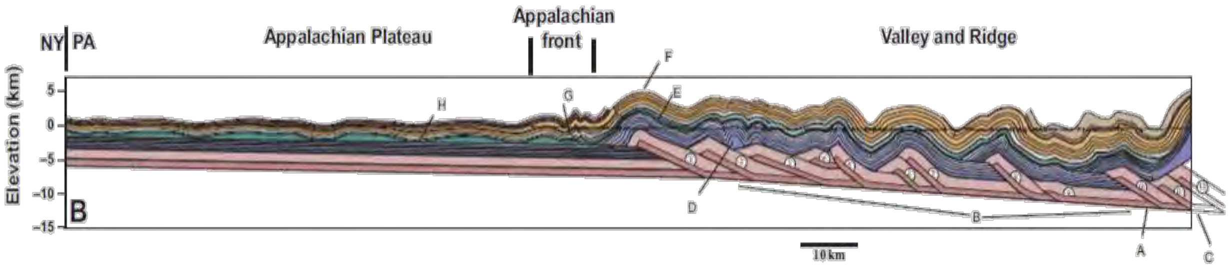

Figure 1: Modified structural cross section from north to south through the Appalachian Plateau, Appalachian/Alleghany Front, and the Valley and Ridge provinces (Sak et al, 2012).

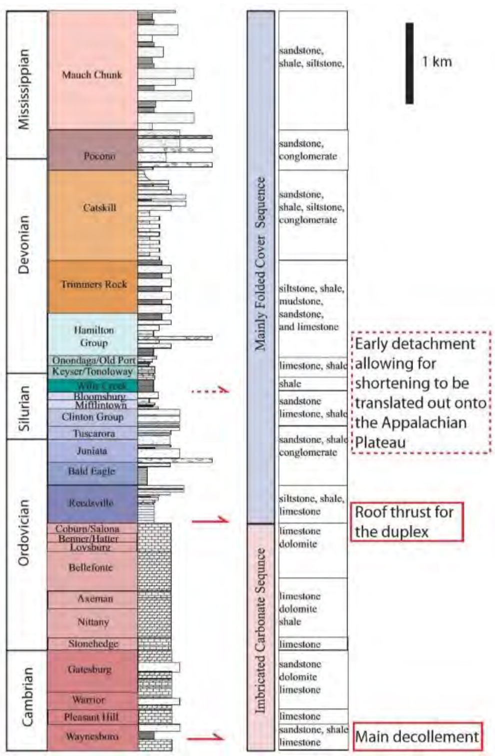

Figure 2: Modified stratigraphic column of the central Pennsylvania Valley and Ridge province with décollement zones(Sak et al, 2012).

References:

Sak, P., Mcquarrie, N., Oliver, B., Lavdovsky, N., Jackson, M., 2012, Unraveling the Central Appalachian fold-thrust belt, Pennsylvania: The power of sequentially restored balanced cross sections for blind fold-thrust belt, Geosphere; June 2012, v. 8: no.3

Evelin Hudson

Evelyn Hudson has been working as an operations geophysicist for over 15yrs. She began her career in June 2005 with Penn Virginia Oil and Gas in Kingsport, TN, and has since worked in Pittsburgh, PA and Fort Worth, TX for Atlas Resource Partners, and is now in Denver, CO for Inflection Energy, LLC. During this time, she has spent her career assisting drilling operations in southern West Virginia, north-central and north-eastern Pennsylvania, southern Mississippi, north and south Texas, and north-central Oklahoma. With Inflection, she is the geophysicist responsible for designing well plans to effectively navigate structural features and overseeing geosteering operations