PS An Investigation of Static and Dynamic Data Using Multistage Triaxial Test*

Abdullah Bilal[1], Michael Myers[1], and Lori Hathon[1]

Search and Discovery Article #42184 (2018)**
Posted March 5, 2018

*Adapted from poster presentation given at 2017 AAPG Annual Convention & Exhibition, Houston, Texas, April 2-5, 2017

[1]Petroleum engineering, University of Houston, Houston, Texas (abilal110@gmail.com)

Abstract

This work is to develop an improved understanding of the relationship between static and dynamic data for a suite of four rock samples. “Static data” are defined as the large strain (> 10^-3) measurements on unloading and reloading tri-axial stress paths. “Dynamic data” are the small strain (<10^-6) data acquired using acoustic velocity measurement techniques. The results are analyzed in terms of Young's Modulus. A quadratic fit has been applied to the static data, this allows us to separate the response into a linear and nonlinear elastic terms. M1, and M2 respectively. M1 is interpreted to be dominated by the contact modulus and is constant throughout the entire unload and reload cycles. M2 the nonlinear elastic term is interpreted to be due to the opening and closing of compliant pores. These interpretations result from the correlation we find between the linear term and the measured velocity and the nonlinear term with the measured irrecoverable strains.

The motivation behind this work is therefore to provide a more robust conversion between the Young's Modulus than that derived from empirically based correlations. It is expected this will ultimately involve the use of thin section and/or microCT data to provide a mineralogical and textural based model, allowing the up-scaled wellbore and field models to be developed. To our knowledge this is the first time a delineation of the separate mechanisms, i.e. linear versus nonlinear effects in the static elastic moduli has been observed. Consistent with previously published results, the dynamic Young's modulus is always greater than or equal to the static modulus. The static Young's Modulus decreases with increasing axial stress. This is interpreted to be consistent with increasing sample damage generating more compliant pores. When the unload-reload cycles are fit with a quadratic equation, the parameters M1 (linear) and M2 (quadratic) were not sensitive to the fraction of the unload-reload cycle data fit at low stress. At high stress the damage associated with initial loading impacts the fit. M1 is equal to the modulus obtained from velocity data at small strains and M2 correlates with the total percent irrecoverable strains on both the unload and reload cycles. M1 is relatively independent of confining stress on the reload cycle. A small stress dependence is observed on the unload cycle. M2 however shows significant stress dependence. M2 decreases with increasing confining stress.

An Investigation of Static and Dynamic Data using Multistage Triaxial Tests.

Abdullah Bilal, [a], Michael T. Myers, [a], Lori Hathon, [a]
[a]Department of Petroleum Engineering, University of Houston
abilal2@uh.edu

Objectives

- This goal of this work is to develop an improved understanding of the relationship between static and dynamic data.
- "Static data" are defined as the large strain (> 10^-3) measurements on unloading and reloading along multistage tri-axial stress paths.
- "Dynamic data" are the small strain (<10^-6) data acquired using standard "pitch and catch" acoustic velocity measurement techniques.
- The results are analyzed in terms of Young's Modulus. A quadratic fit has been applied to the static Young's modulus data, this allows us to separate the response into a linear and nonlinear elastic terms. M1, and M2 respectively.
- M1 is interpreted to be dominated by the contact modulus, and is constant throughout the entire unload and reload cycles.
- M2 the nonlinear elastic term, is interpreted to be due to the opening and closing of compliant pores. These interpretations are based on the correlations we find between the linear term and the measured velocity and the nonlinear term with the measured irrecoverable strains.

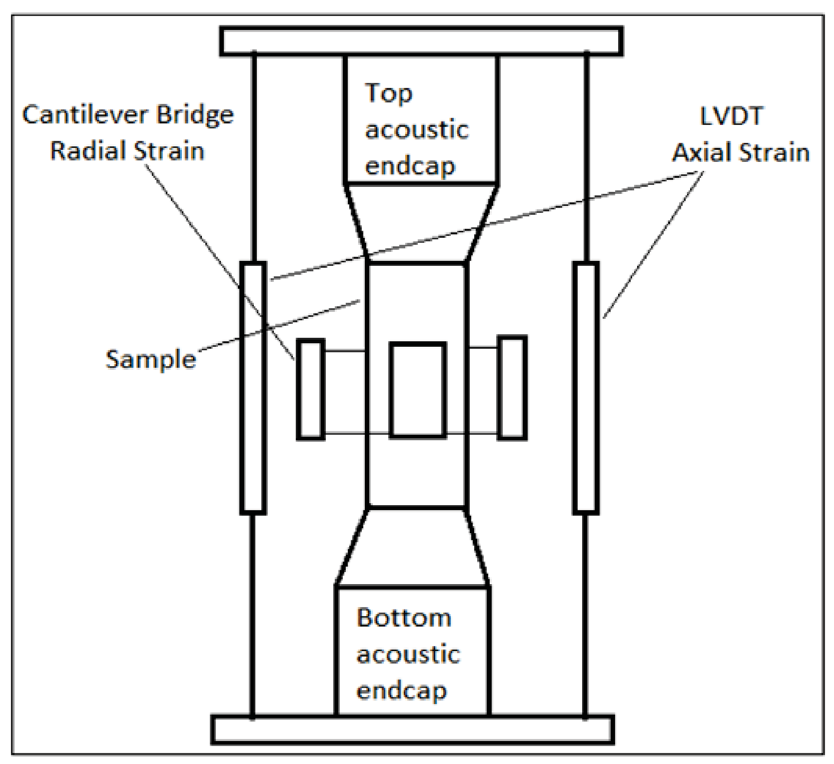
Importance

- Wellbore failure: predict failure.
- "Frackability": some brittleness index, fissure fractures, correlate on irrecoverable strains.
- Populating 4D seismic model: anisotropy, plane wave models.
- Reservoir simulation: compressibility.
- Sand Control: maximum compressive strength.
- Material Models: go beyond Young's Modulus and Poisson's ratio, static and dynamic data are part of the puzzle.

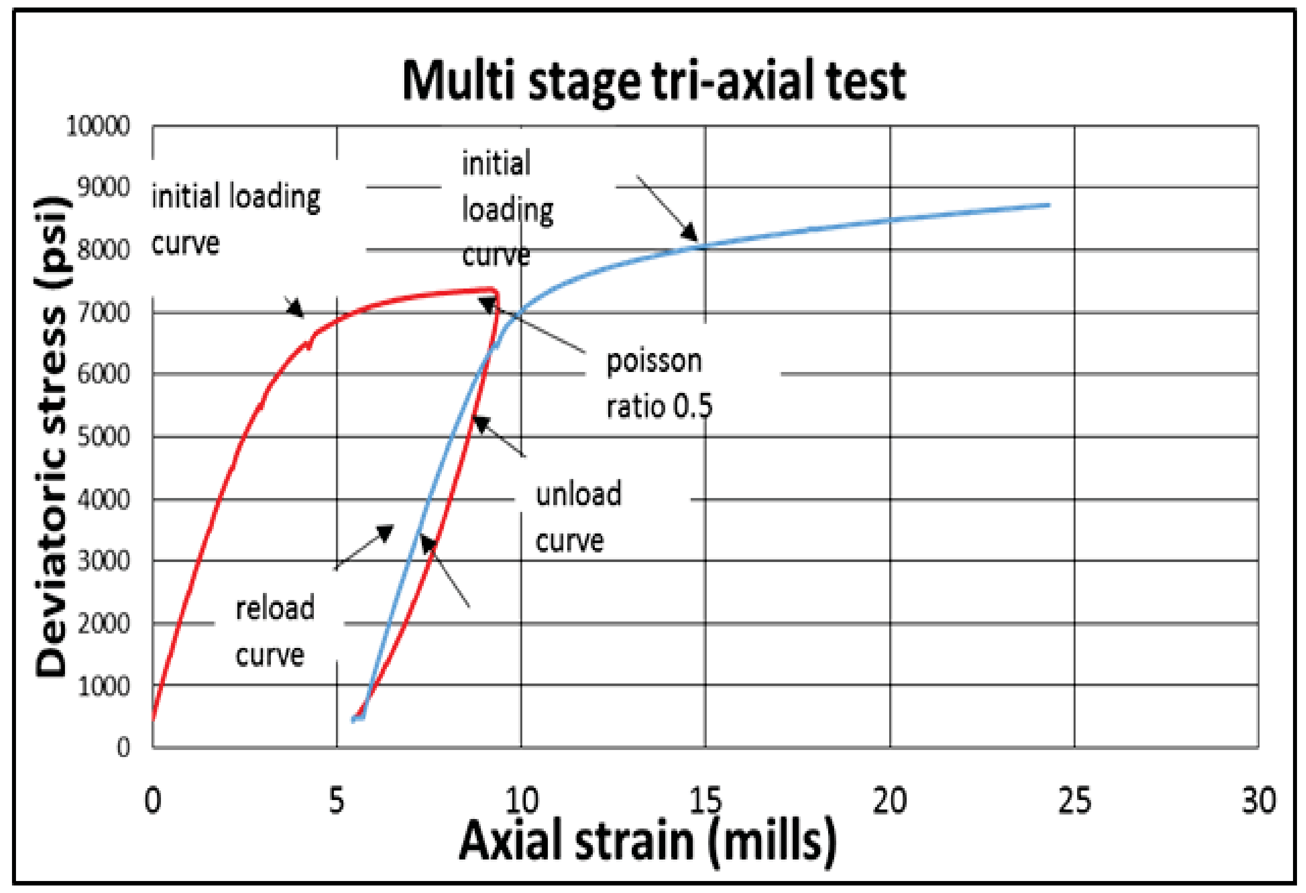
Factors effecting static and dynamic data

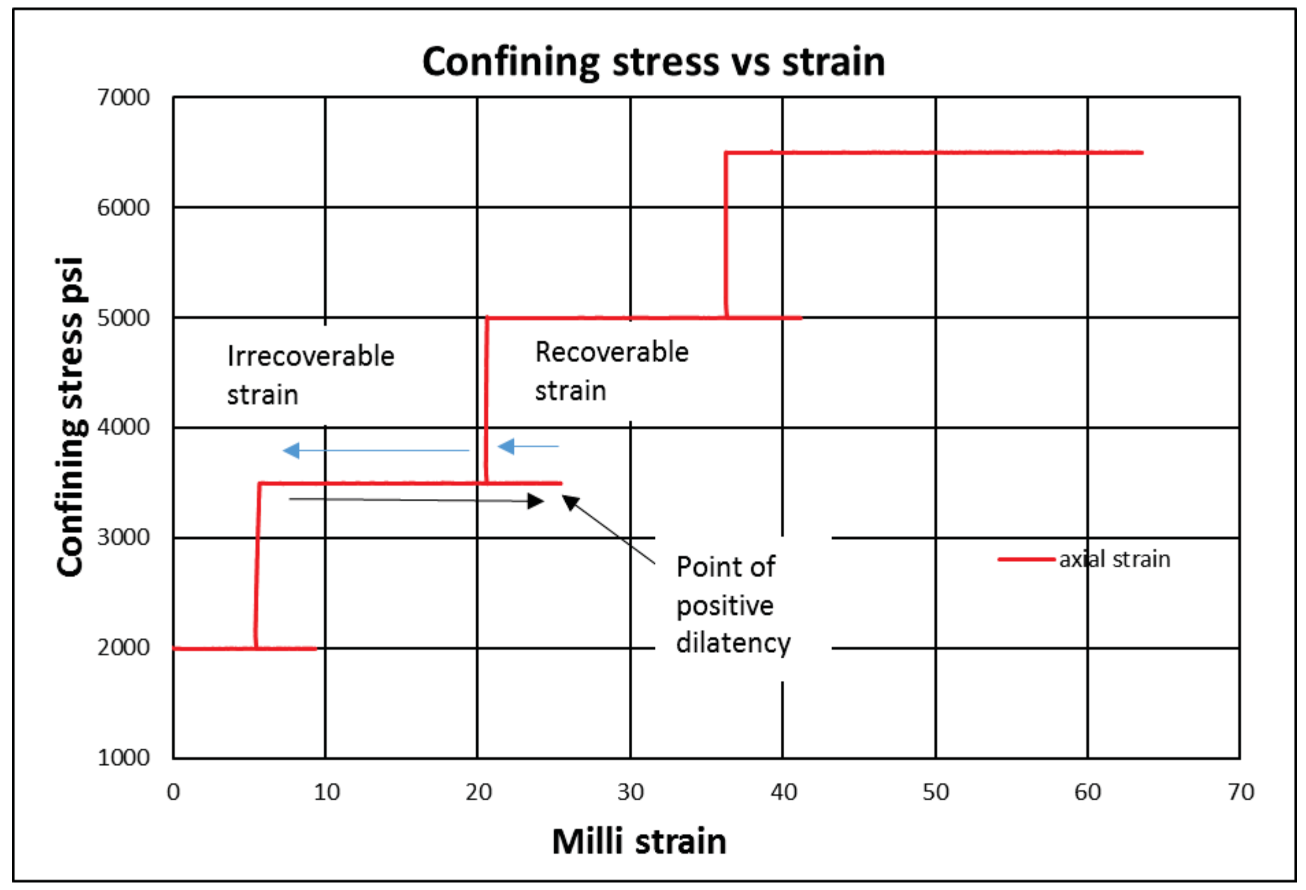
- Organics: Mainly unconventional tight formations, responsible for ductile deformation.
- Thermal Maturity: Effects modulus.
- Porosity: volume of materials, grain vs matrix, frame and contact modulus, grain cracking at higher porosity.
- Clay content: load bearing will increase irrecoverable strain, non-load bearing impact velocity.
- Cementation: small volume of cements can impact significantly.
- Anisotropy: Velocity propagates different in different direction.
- Stress history: rock memory.

Experimental Setup



Multistage triaxial test (MST)



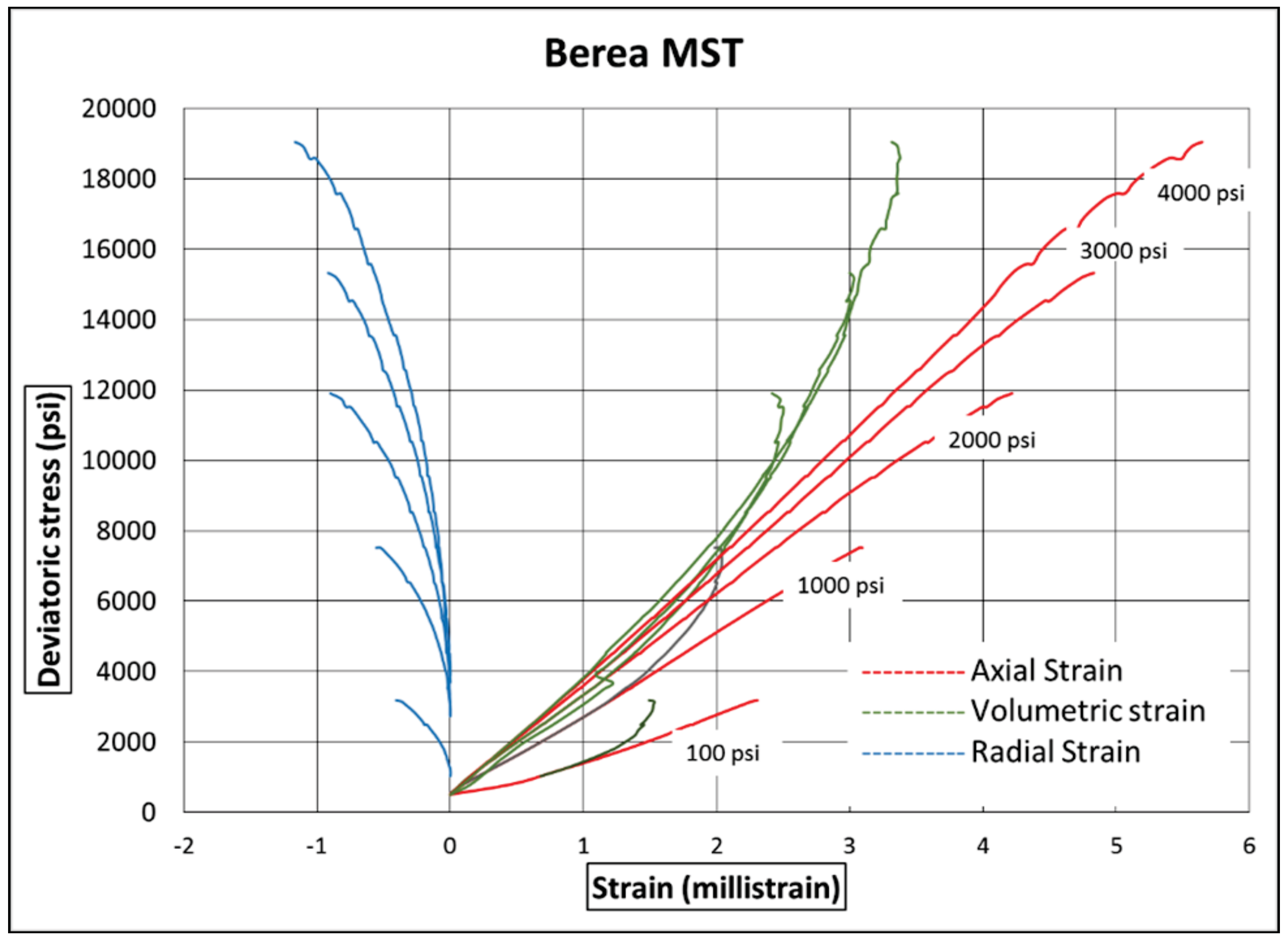


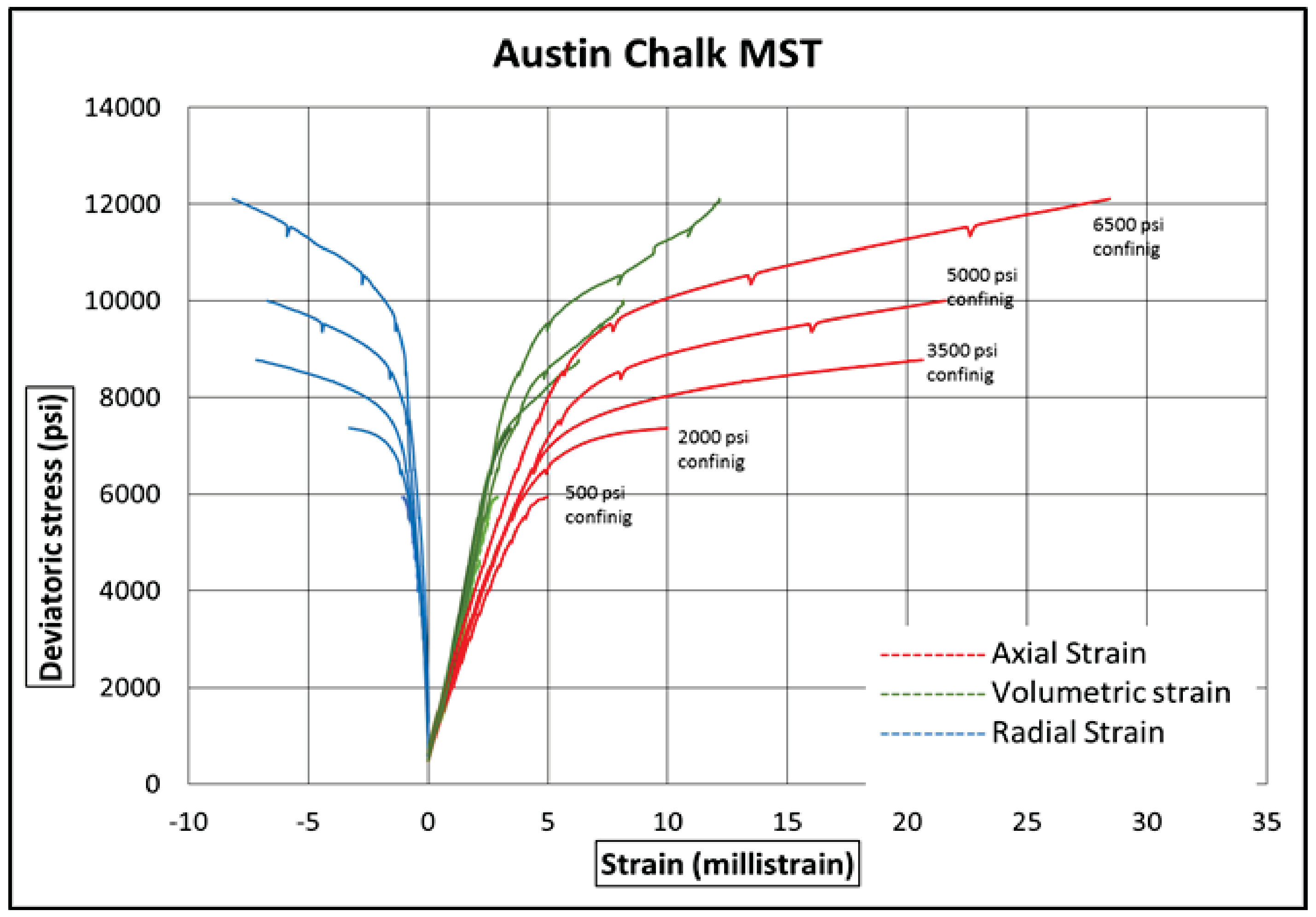
- In a MST, deviatoric stress is raised (initial loading curve) till the sample reach the point of positive dilatency (PPD).
- PPD is that point where poison ratio reaches half. After that the sample is unloaded (unload curve) to a low deviatoric stress. Then the confining stress is raised and the same thing (reload curve) is repeated at the new confining stress
- Failure stress is 1.2 times the stress at the point of positive delatency. (salman et al. Arma 2015)

An Investigation of Static and Dynamic Data using Multistage Triaxial Tests.

Abdullah Bilal, [a], Michael T. Myers, [a], Lori Hathon, [a]
[a]Department of Petroleum Engineering, University of Houston
abilal2@uh.edu

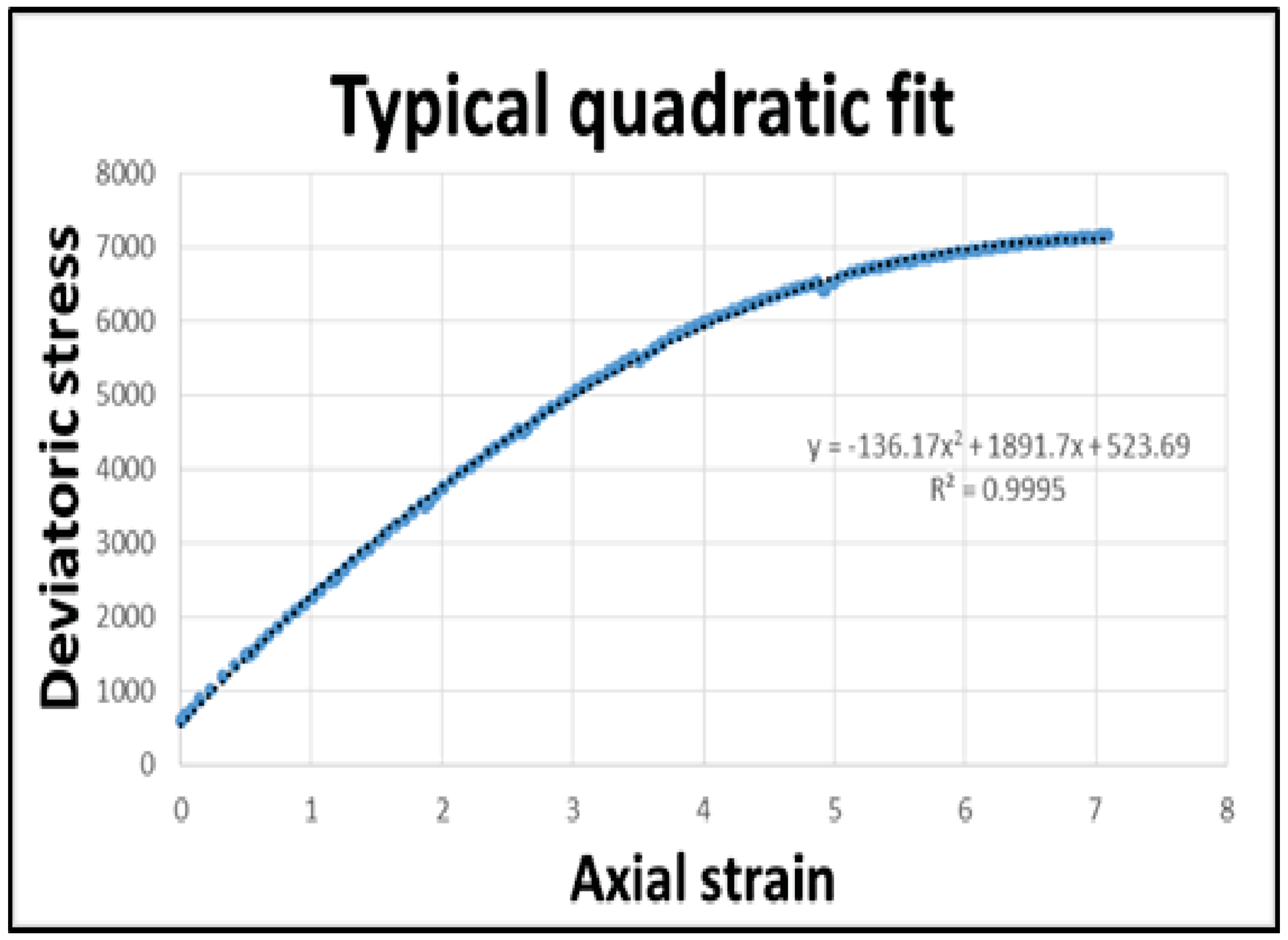
Fountain Plot Multistage Triaxial test

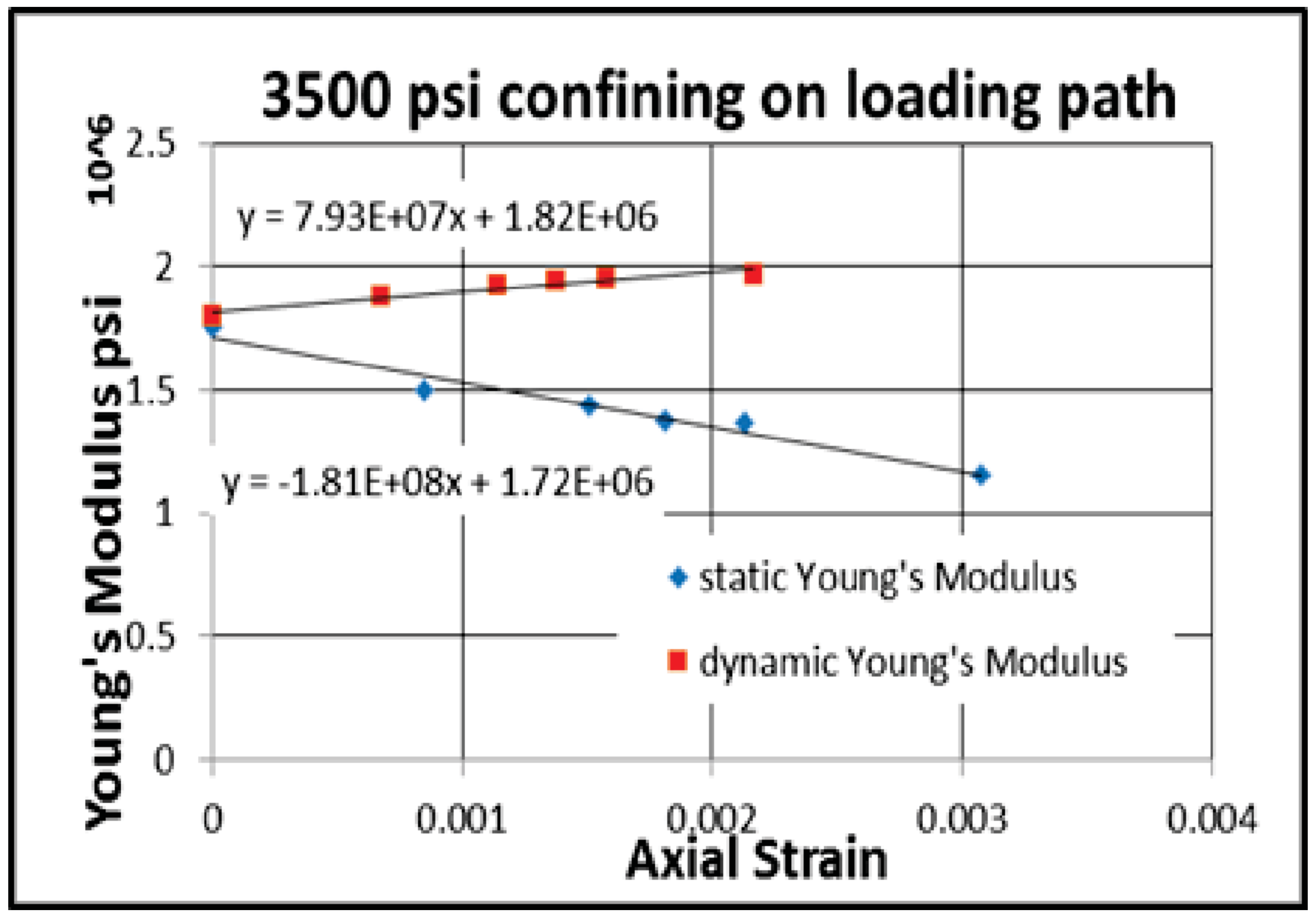




- Plot of axial, radial and volumetric strains vs deviatoric stress.
- Berea and Austin Chalk represent the range of samples in term of plastic deformation, that we have worked on.
- Significant Effect of confining pressure on the slope of stress vs strain graph in case of Berea than Austin Chalk.

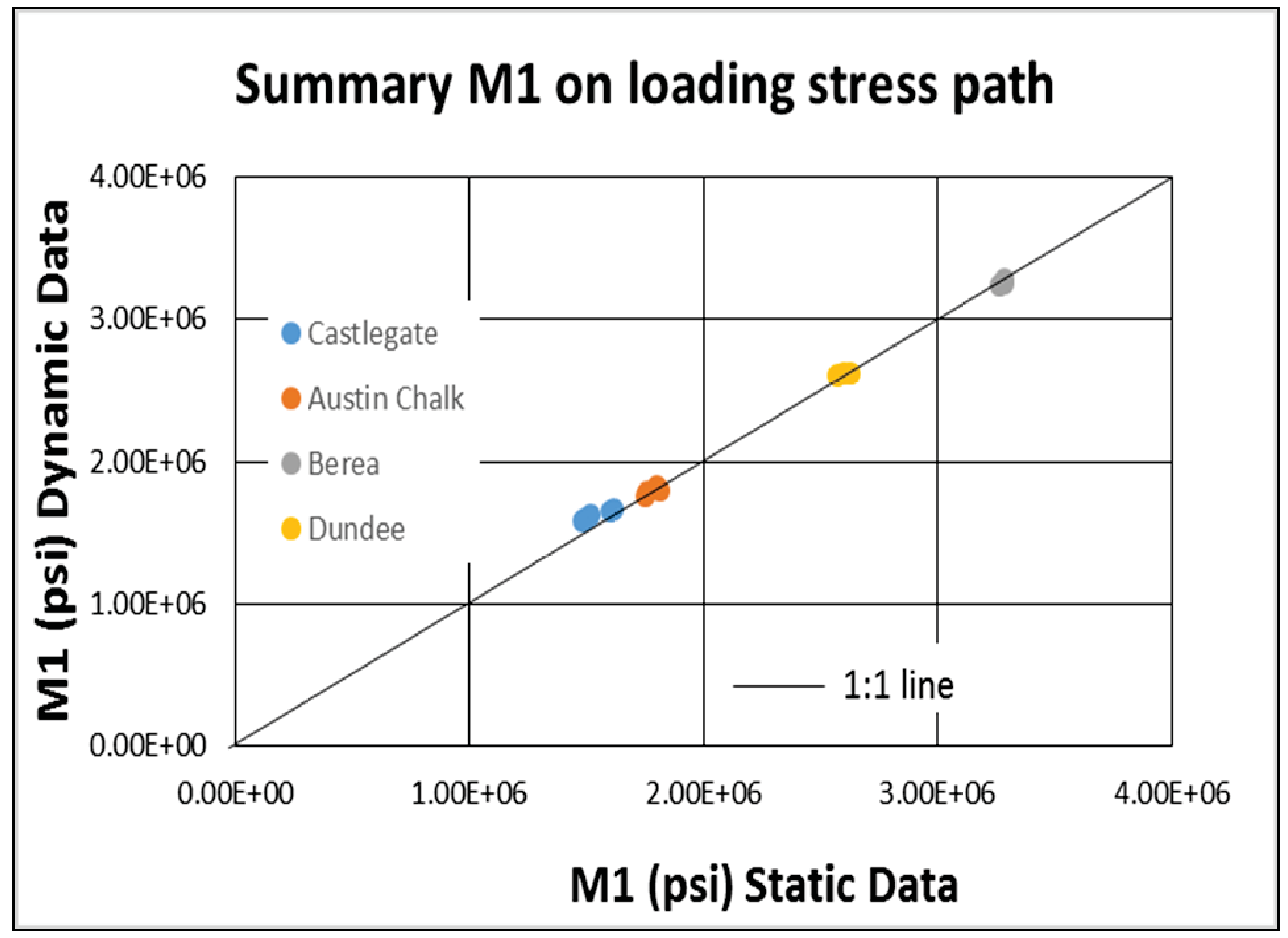
Quadratic fit for static vs dynamic data

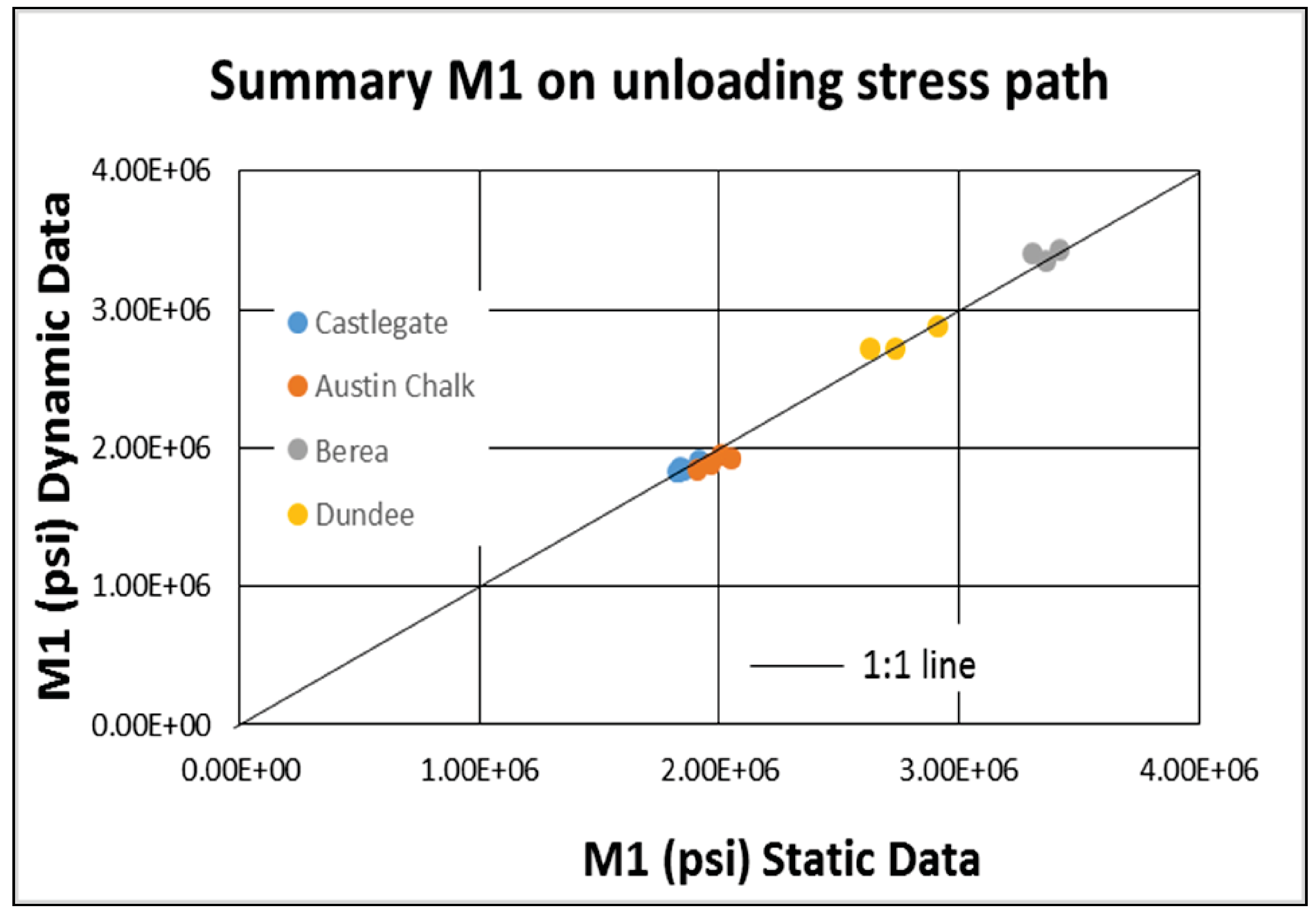




- σ = $M_2\varepsilon^2 + M_1\varepsilon + \sigma_0$
- Where σ is the stress for a certain strain ε.
- M_2 is named to be "Hyper Modulus" which is half times the slope of static young's modulus vs strain.
- M_1 is the small strain young's modulus which is same for both static and dynamic data.
- The static and dynamic Young's modulus are equal at small strains as found by Fjaer et.al , ARMA (2015) .

Summary plots for M1



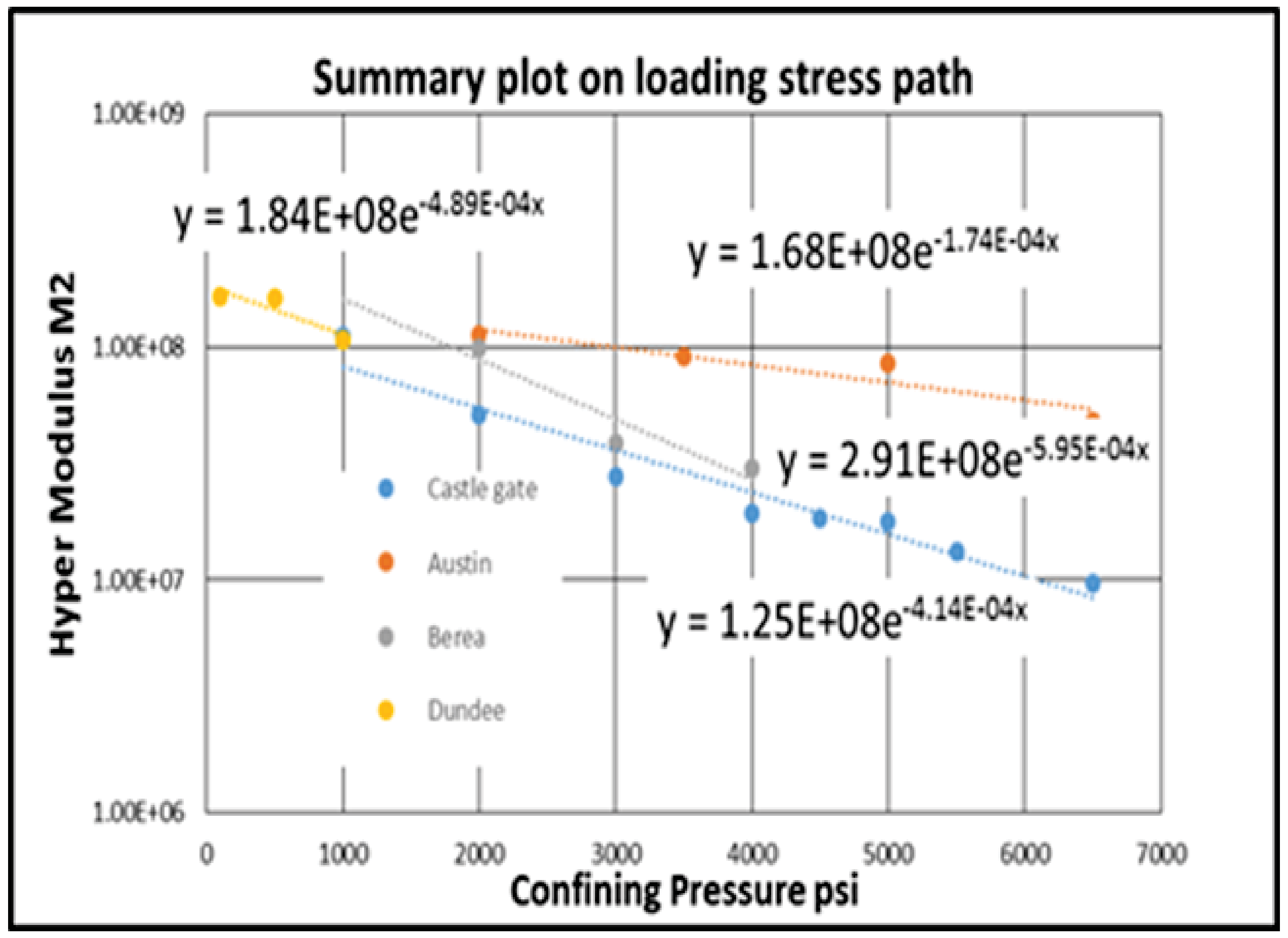


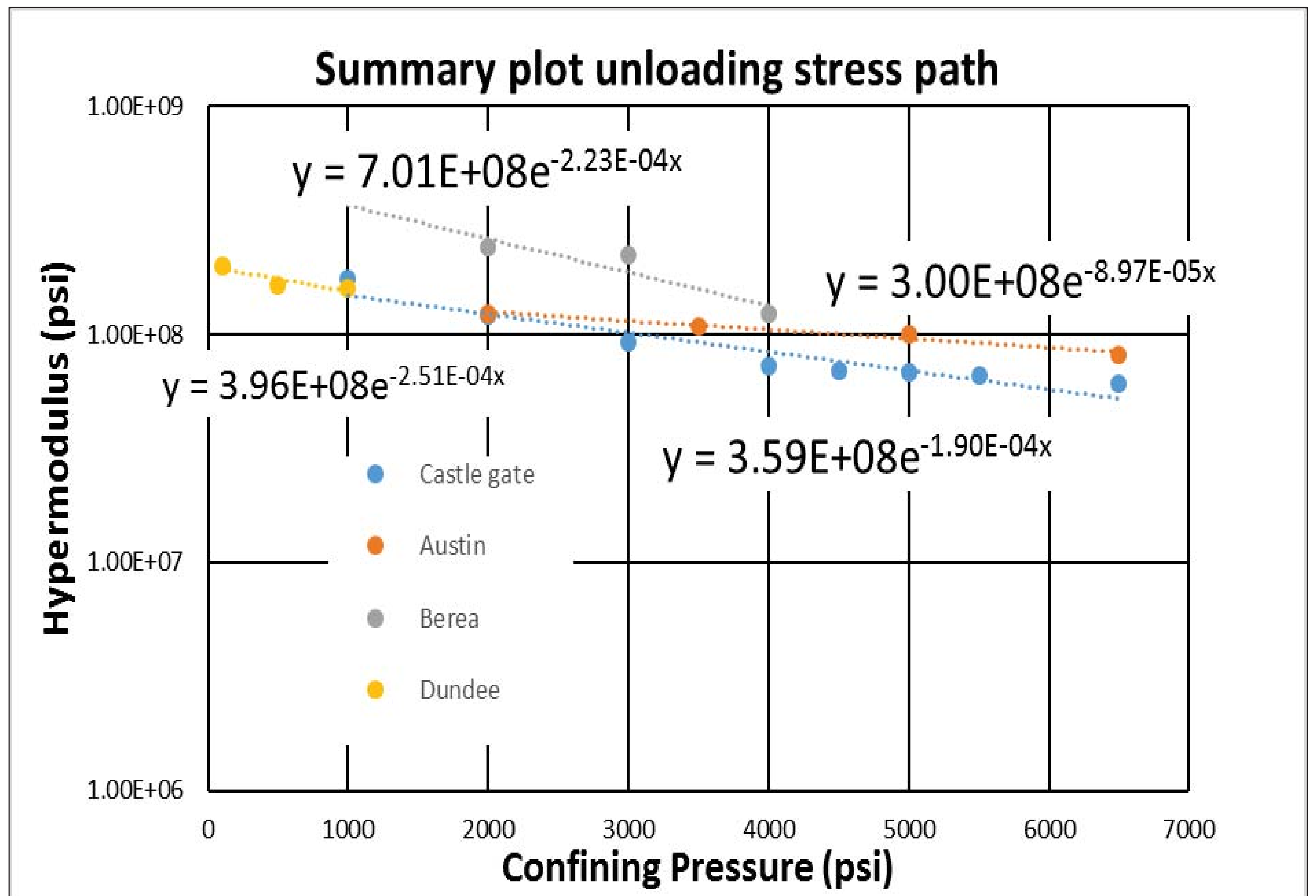
- The fit to the stress-strain data, therefore, should give M1 equal to the modulus derived from the velocity data as observed in in above figures.
- Dynamic vs static M1 on the loading stress path. They are equal within the experimental error. There are multiple points for each sample implying a small stress dependence for each sample compared to the differences between samples.

An Investigation of Static and Dynamic Data using Multistage Triaxial Tests.

Abdullah Bilal,[a], Michael T. Myers, [a], Lori Hathon,[a]
[a]Department of Petroleum Engineering, University of Houston
abilal2@uh.edu

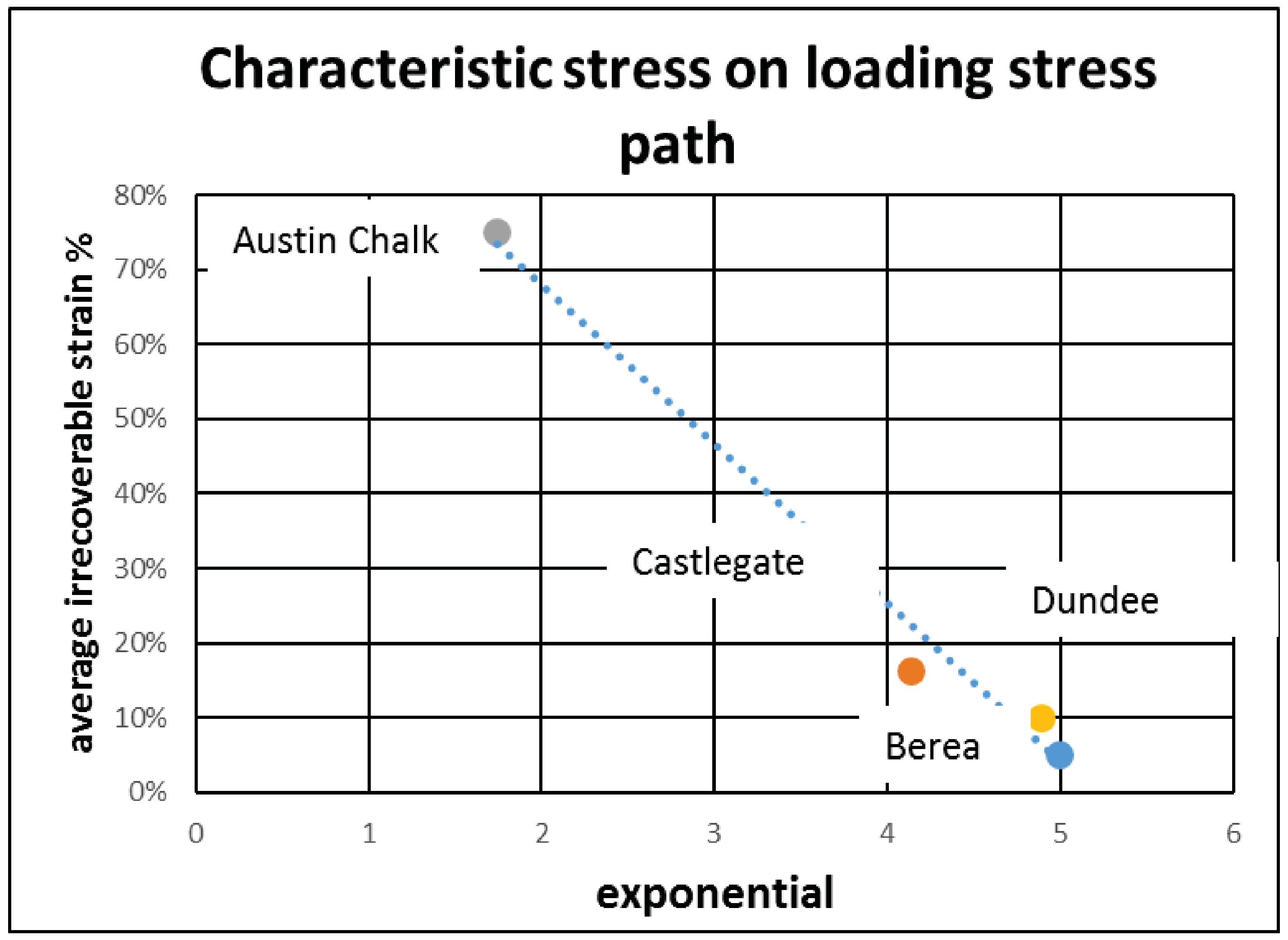
Summary plots for M2

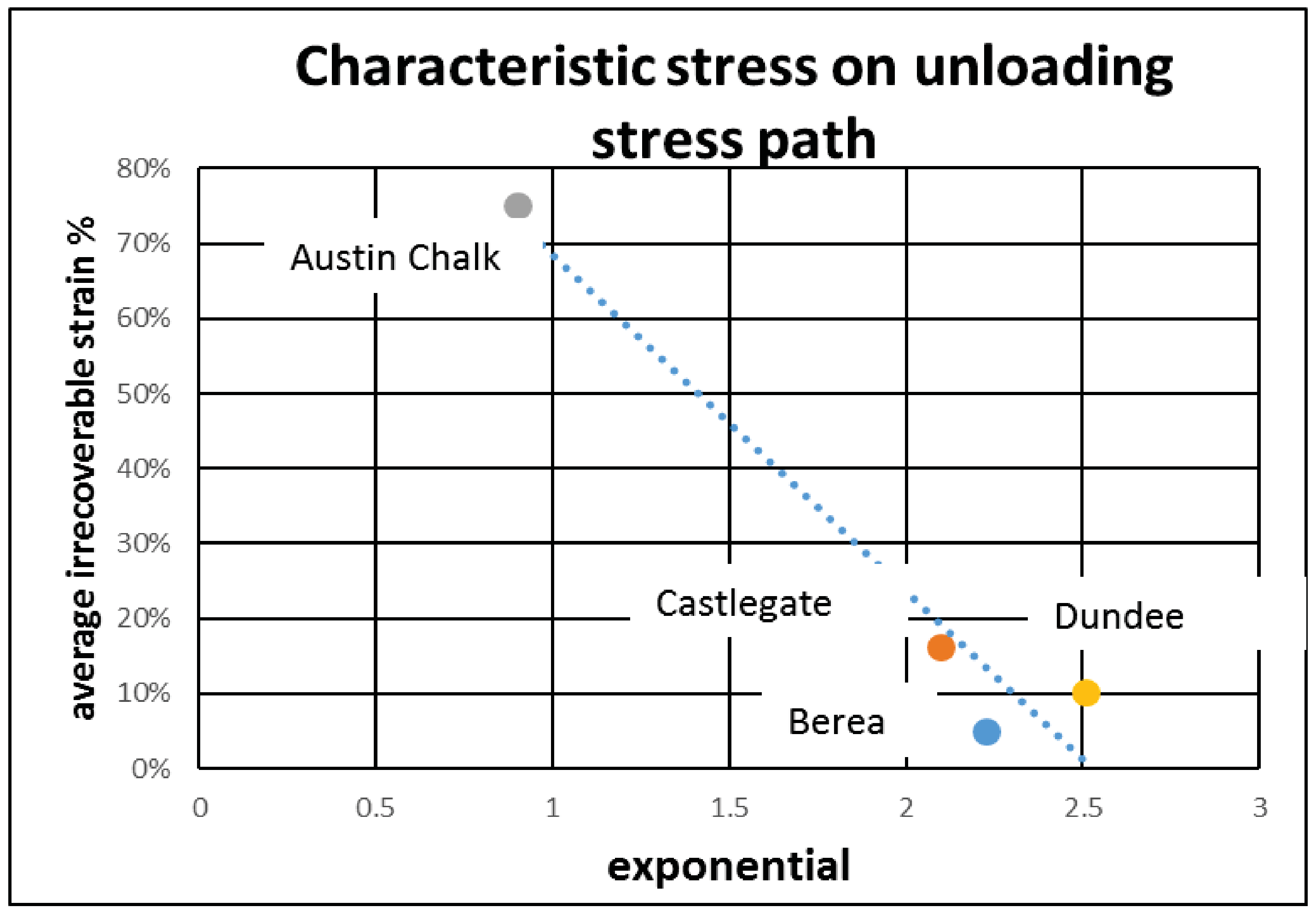




- The second order term in quadratic fit is defined to be Hyper modulus M2.
- We have analyzed M2 in terms of confining pressure.
- With increasing confining pressure the absolute value of M2 decreases.
- At lower confining pressure the M2 converges to a single value for all the rock types.

M2 vs irrecoverable strains





- Percent irrecoverable strain and characteristic stress has linear relationship between them.
- Higher irrecoverable strain means that M2 depends less on confining pressure than as compared to lower irrecoverable case.
- Irrecoverable strains can also give a qualitative estimate of plastic deformation in the samples.

Conclusions

- To our knowledge this is the first time a delineation of the separate mechanisms i.e. linear versus nonlinear effects in the static elastic moduli has been observed.
- The dynamic Young's modulus increases with increasing axial stress. This is interpreted to be due to the stress effects on the contact modulus. i.e. a Hertzian contact model.
- The static Young's modulus decreases with increasing axial stress. This is interpreted to be consistent with the increasing sample damage generating more compliant pores.
- M1 is equal to the modulus obtained from velocity data at small strains and M2 (hypermodulus) correlates with the total percent irrecoverable strains on both the unload and reload cycles.
- M1 is relatively independent of confining stress on the reload cycle. A small confining stress dependence is observed on the unload cycle. The hypermodulus (M2) however shows significant confining stress dependence. M2 decreases with increasing confining stress. This is consistent with these pores stiffening with increased stress.

References

1. E. Fjaer, Holt, Stroisz (2015) "Static vs Dynamic Moduli: another piece in the puzzle", ARMA conference 2015.
2. Alsalman, M.E, Myers M.T. Aldin M (2015) "Comparison of Multi-Stage to Single-Stage Tri-Axial test". ARMA conference.
3. Larsen, Fjaer, Renlie (2000) "Static and dynamic Poisson's ratio of weak sandstones" Pacific Rocks.
4. A Taheri, K Tani (2008) " Proposal of a new Multiple-Step loading Triaxial Compression Testing Method" ISRM International Symposium.
5. Kovari, K and A. Tisa (1975) "Multiple failure state and strain controlled triaxial tests" Rock Mechanics.
6. Hertz, H.R, 1896 "On contact between elastic bodies" in Collected works, Vol 1, Leipzig Germany.
7. Bilal, Myers, Hathon A (2016) "An investigation of static and dynamic data using multistage triaxial tests" (Arma 2016)