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Grenvillian Tectonomagmatic Evolution Of Southwestern Laurentia; Virtual Tour Of Multidimensional Orders Of Scale; Two Methods To Describe The Vastness Of Time; Math Concepts Utilizing Google Earth; Systematic Approach To Motion Analyses; Mathematics And Earth Science-Based Knowledge And Learning

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GRENVILLIAN TECTONOMAGMATIC EVOLUTION OF SOUTHWESTERN LAURENTIA; VIRTUAL TOUR OF MULTIDIMENSIONAL ORDERS OF SCALE; TWO METHODS TO DESCRIBE THE VASTNESS OF TIME; MATH CONCEPTS UTILIZING GOOGLE EARTH; SYSTEMATIC APPROACH TO MOTION ANALYSES; MATHEMATICS AND EARTH SCIENCE-BASED KNOWLEDGE AND LEARNING TRENDS: A MULTI-TIERED INVESTIGATION AND RATIONALE

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Dedication

This dissertation is dedicated to my children. I remember taking you to Earth Day at the Geology Department when you were young, now you are grown and even attending UTEP. You made me come to the realization that it was time to finish.

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DISSERTATION

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I would like to express my gratitude to my chair Philip Goodell. You have taught me more than any other individual on this planet, and for that I am grateful. I would also like to thank all the other members of my committee for their contributions. Richard Jarvis, you helped me maintain my sanity. Eric Kappus, you have been a vital mentor and my rock through the whole process. Munazzam Ali Mahar, you helped me learn new techniques and analyses relevant to my research, and Aaron Velasco, you made me realize the finish line was not too far away. Mourat Tchoshanov, you took me under your wing and served as my mentor. I would also like to thank Mercedes Guzman, Laura Serpa, Olga Kosheleva, and Kien Lim because each of you provided support and guidance in your own special way. I am a better individual because of every one of you.

Abstract

This dissertation is the product of several individual multi-disciplinary investigations that cover a variety of topics in mathematics, physics, geology, and geoscience education. The first chapter formulates a better understanding of the timings, magma source, and relationships between dikes and associated magmatic bodies of the Red Bluff Granitic Complex to provide a clearer picture of the evolution of post-Grenville magmatism and tectonism of southwestern USA. The second chapter provides an improved method for representing spatial information in the form of a multidimensional virtual tour where the background map is used as a central object. The third chapter describes two methods to describe the vastness of time: the first a geo-spatial and chronologically organized virtual tour and the second calculates the date of the El Paso/Juarez regional formations proportionally to a 12-month calendar. The fourth chapter describes methods to utilize Google Earth™ to solve for the slope of a path frequently traveled and a new technique for manipulating polygons to calculate volume and surface area. The fifth chapter describes a methodological approach of incorporating motion analysis-based software within the classroom. The sixth chapter discusses the methods and outcomes for a two-year professional development grant for mathematics and Earth science teachers. The primary goal of the program was to encourage teachers to integrate these disciplines into their classrooms.

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Chapter 1: Grenvillian Tectonomagmatic Evolution of Southwestern Laurentia

Abstract

Precise timing and characterization of magma sources are critical to better understand the tectonomagmatic and geodynamic evolution of southwestern margin of Laurentia. In this work, we integrated our new zircon U–Pb ages and Hf isotope composition with previously compiled data to provide a more coherent understanding of the magmatic evolution in the overall regional lithotectonic setting. This paper provides LA–MC–ICP–MS U–Pb geochronology and LA–MC–ICP–MS time-constrained zircon Hf isotope composition on five samples from two stages of the Red Bluff Granitic Suite (RBGS) and two samples from ferroan basalt dikes within the Franklin Mountains of El Paso, Texas. Zircon U–Pb geochronology yielded Concordia ages of 1121.3 ± 2.9 Ma and 1118.4 ± 5.4 Ma for the stage-1 syenite and main body of stage-2 granite, respectively. The basaltic dikes yielded a similar weighted mean age of 1124 ± 14.1 Ma. Our new zircon U–Pb ages coupled with the previous geochronological efforts revealed the subtle differences in the timing of emplacement for the different stages. In fact, U–Pb ages are overlapping within the error. This suggests that the earlier less-evolved magmas and subsequent more differentiated magmatic bodies emplaced within a short span of time not more than 3 Ma. We consider the concordant dates those are 10 to 20 Ma older than the weighted mean/Concordia age as the antecrystic zircons. The range for antecrystic zircons is from 1130 to 1138 Ma. Xenocrystic inheritance from 1141 to 1260 Ma also occurred. The initial Hf isotope composition of the studied plutons remained mostly positive. The weighted mean εHf (t) for the stage 1 and 2 varies from +5.3 to +7.2. Two basaltic dike samples revealed the similar but more hetrogenous εHf (t) values with weighted mean εHf (t)

values of +5.2 to 6.7. Geochemistry shows all the RBGS, granitic dike, and mafic dikes plot as A2-type anorogenic granites. These units also all plot within-plate, as fractionated granites, and have many elements equal or nearly equal when normalized to OIB. Anomalies in Eu is typical of a feldspar fractionated trend, and flatter HREE patterns might suggest magma was generated at the garnet stability field or sequestered out. Lower Ta and Nb relative to adjacent elements is typical of island arc basalts and could mean mantle-derived source(s). Given the absence of older inheritance such as 1.65-1.60 Ga Mazatzal, geochemistry, and radiogenic Hf isotopic compositions of the Red Bluff granites, a minimal contribution from older Mesoproterozoic crust is suggested. Based on the timing and geochemical composition, we suggest that the magmatism at the Franklin Mountains and Llano Uplift recorded the partial melting of the Subcontinental Lithospheric Mantle at around 1.1 Ga, possibly, during a rifting event initiated by block rotation after the development of a convergence zone of southwestern Laurentian Front. Alternatively, partial melting of a juvenile recently-placed basaltic (amphibolite) underplate is suggested.

1. Introduction

The magma source region history and its implications for the regional thermotectonic evolution of Post-Grenvillian southwestern Laurentia remains elusive (Bickford et al., 2000; Mosher, 1998; Mosher et al., 2008; Shannon et al., 1997). The Grenville Orogeny contains the compression cycles of the 1090-1020 Ma Ottawan Orogeny and the 1000-980 Ma Rigolet Orogeny and no longer includes the 1190-1140 Ma Shawingian Orogeny (McLelland et al., 2010; Rivers, 2008), but for the purposes of this paper will refer to ages from 1.3 to 1.0 Ga as Grenvillian. Grenvillian magmatic rocks have been interpreted as the product of subduction-related magmatism (e.g., Nelson and DePaolo 1985; Norman et al., 1987; Roths, 1993). The A-type magmatic rocks of southwestern Laurentia might have produced by back-arc spreading (Mosher, 1998; Norman et

al., 1997) or a retroarc basin (Mulder et al., 2017). Other processes might include slab break-off (Mosher et al., 2008), and slab break-off that was coinciding with block rotation (Davis & Mosher, 2015). However, magma generation is also directly related to the anorogenic continental rift setting (e.g., Adams & Keller, 1994; Bickford et al., 2000; Kargi & Barnes 1995; Keller et al., 1989; Norman et al., 1997; Shannon et al., 1997). Barker & Reed (2010) and Smith et al. (1997) suggested vertical magma migration by lithosphere being replaced by upwelling asthenosphere during convergence. This is evident by the intrusion of mafic dikes, mantle-derived melts, and syncollisional extension (Corrigan & Hanmer, 1997). Corringan and Hanmer (1997) proposed three possibilities: 1) juxtaposition of hot asthenosphere with thinned continental lithosphere, 2) increase in the potential energy of the crust, or 3) a thermal pulse in the extended crust. Mosher (1998) suggested that the Red Bluff Granitic Suite (RBGS) and Pecos Mafic Intrusive Complex (PMIC) were formed by parallel east-west extensions, creating north-south trending structural features.

The Franklin Mountains are part of the west Texas Mesoproterozoic magmatism characterized by bi-modal intrusive and volcanic rocks. The RBGS is a suite of continuous variable composition from quartz syenite to leucogranites from coeval basaltic magmas. The magmatic rocks are classified as a metaluminous, within-plate, A-type granitic suite which intruded the Proterozoic shelf and emplaced at 1120 ± 35 Ma within the few kilometer depth (Shannon et al., 1997). To date, the sequence of stages of the RBGS is based mainly on field relations, many of which contradict each other. In the present work, we provide zircon U-Pb and Hf isotope composition of spatially-related granitic and basaltic rocks emplaced within the RBGS. This coupled with previous U-Pb-Hf compiled data, and regional geochemical evolution provides more robust constraints to understand the timing, magma sources with implications for the

geodynamic evolution of post-Grenvillian Southwestern USA. The tectonic configuration of Laurentia is then be used to discuss similar or different post-Grenvillian aged regional magmatism. The Franklin Mountains, Pikes Peak Batholith, and the Llano Uplift share three distinct magmatic ages, and there is a trend for a higher initial Hf values for the older magmatic bodies.

2. North American Orogenies 1.7-1.0 Ga

Nuclei of the North American continent formed by continental collisions from 2.0-1.8 Ga as shown in Figure 1 (Whitmeyer & Karlstrom, 2007). The mid-continent region within Laurentia spans the area between exposed basement of the Rocky Mountains to the west, the Appalachian Mountains to the east, southern Texas, and north toward the southern plains of Saskatchewan (Bickford et al., 2015). The lithosphere of the southern United States formed with additions of predominately juvenile volcanic arcs and oceanic terranes horizontally sutured along the southern plate margin (Whitmeyer & Karlstrom, 2007). Orogenies of crustal formation provinces include 1.70-1.68 Ga Yavapai, 1.65-1.60 Ga Mazatzal, 1.48-1.35 Ga Picuris orogeny, 1.45-1.30 Ga Granite-Rhyolite, and the 1.30-1.00 Ga Llano-Grenville (Aronoff, 2016; Bennett & DePaolo, 1987 and Whitmeyer & Karlstrom, 2007). During each orogeny, juvenile lithosphere that was added gave rise to stable continental lithosphere via granitic plutonism (Whitmeyer & Karlstrom, 2007). Exhaustive discussion about the older inland cratonic geology is out of the scope of this paper, in the following, we briefly describe some salient features and present understanding about the evolution of southwestern Laurentia, particularly during 1.3-1.0 Ga. all the basement provinces are shown in the Figure 1.

There is no consensus on the Picuris and Grenville orogenies. Magnetic or gravity data cannot distinguish the Nd-line that extends from southwest Texas to southeastern Michigan (see Figure 1.), but distinctly separates crust containing pre 1.6 Ga juvenile components to the

northwest and post 1.6 Ga juvenile components to the southeast (Bickford et al., 2015; Yang et al., 2017). Felsic intrusive and extrusive bodies affected a large part of the underlain areas of the Yavapai and Maztzal provinces from 1.55 to 1.35 Ga forming the Granite-Rhyolite province (Yang et al., 2017). Figure 1a shows these Laurentian basement providences. The final formation of Rodinia, the intracratonic extension, and voluminous magmatism from ~1.3-1.09 Ga resulted in consequent structures such as the Granite-Rhyolite and Grenville provinces and Keweenawan magmatism (Li et al., 2008; Yang et al., 2017). This Grenvillian (i.e., ~ 1.1 Ga) magmatism is the subject of this study.

The Picuris orogeny spans from northern New Mexico to southern Colorado and is linked to the 1.51-1.45 Ga Pinware orogeny of eastern North America (Aronoff, 2016). The Yavapai, Mazatzal, Pinware, and Picuris orogenies were all products of convergence along southern margins (Aronoff, 2016). Even though Proterozoic rocks in Colorado experienced high-temperature metamorphism during the Yavapai, Mazatzal and Picuris orogenies, and that New Mexico was previously thought to be a transition zone between Yavapai and Mazatzal rocks, portions of New Mexico did not undergo high-temperature metamorphism until the Picuris orogeny (Aronoff et al., 2016). Aronoff et al. (2016) also show that thrust-sense shear zones separated amphibolite facies metamorphism and deformation of northern New Mexico and ages of garnets growth and deformed in different constrained generations of 1.46-1.45 Ga, 1.42-1.40 Ga and after 1.40 Ga during a single tectonic/metamorphic event.

The Rocky Mountain Front forms a structural boundary between thick cratonic lithosphere to the (present day) east and orogenic plateau to the west (Chapin et al., 2014). The Rocky Mountain Front formed between 1.4 and 1.1 Ga which was reactivated between 1.1 to 0.6 Ga during the breakup of Rodinia, and (1.09 Ga) Pikes Peak batholith intruded the Granite-Rhyolite

Province in central Colorado (Chapin et al., 2014). Magmatism from 1094 to 1080 Ma was renamed by Bright et al. (2014) as the Southwestern Laurentia large igneous province (SWLLIP). This region was initially proposed by Hammond (1990). Bright et al. (2014) proposed a mantle plume that split into two directions; north to the Keweenawan large igneous province due to extensional forces and decompression melting from the underlying plume and south to regions of thinner lithosphere forming the SWLLIP.

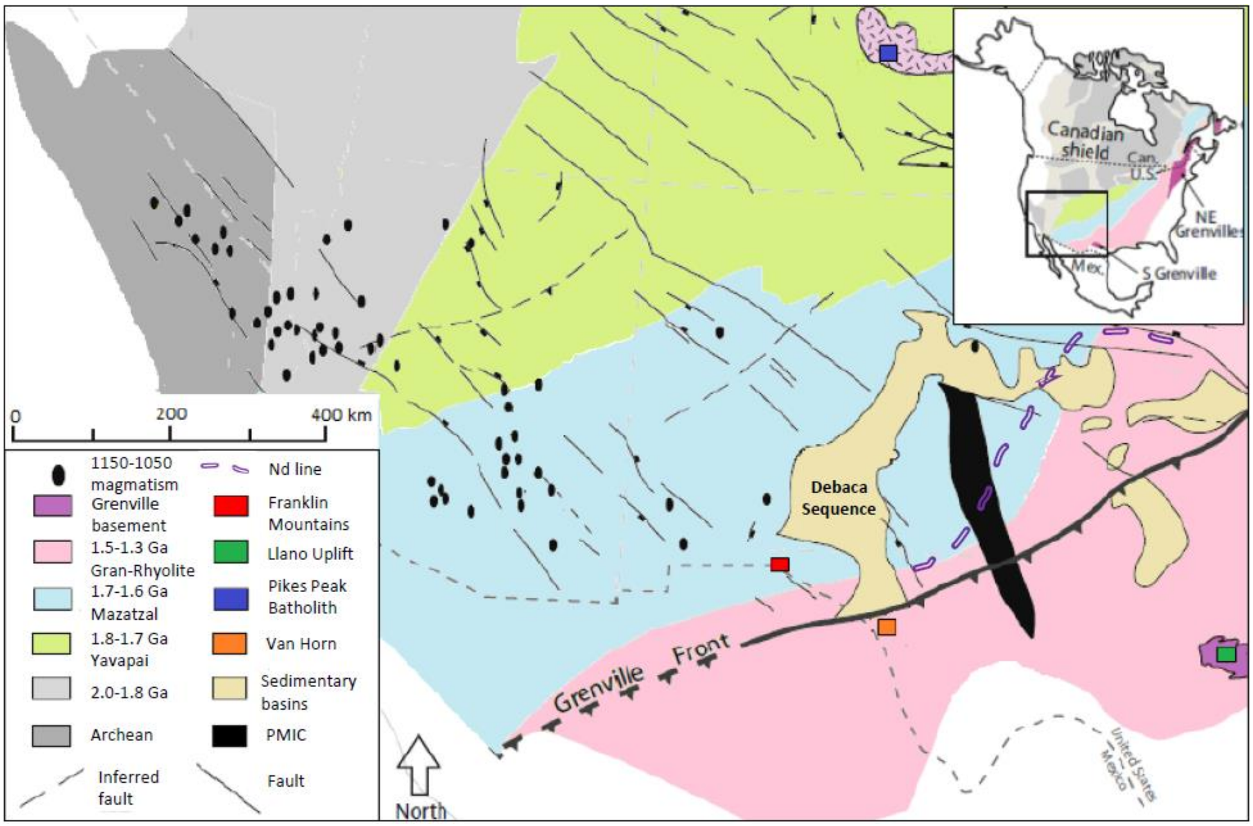


Figure 1. Location map of the Franklin Mountains showing Basement provinces of 1.1 Ga Laurentian providences, modified from Mulder et al. (2017) and reference map.

3. Local Geologic Setting of the Franklin Mountains

The Franklin Mountains (FM) are the southern-most range in a series of NS-trending mountains extending from central New Mexico to within the westernmost tip of Texas (as shown in Figure 1). The FM average five km in width (McCutcheon, 1982) and represent a tilted, uplifted

fault-block dipping approximately 30˚to the west with steep east facing scarps (Harbour, 1972). Several transverse and longitudinal faults cut the range (Harbour, 1972; Lovejoy, 1975). The FM preserve deformation related to both crustal shortening during the Laramide orogeny and crustal thinning and extension due to development of the Rio Grande rift (Carciumaru & Ortega, 2008). The fault block attained its present-day physiography during this later rifting event and currently forms an extensional uplift within the southern Rio Grande rift. The main east-dipping normal fault that extends the length of the entire uplift confines the eastern margin of the fault block. The Franklin Mountains contain numerous magmatic bodies with varying ages and compositions; granitic and associated volcanic rocks cover an exposed distance of 25 km from north to south (Shannon et al., 1997). The Franklin Mountains are composed of units spanning from Precambrian to Holocene in age (Harbour, 1972).

Table 1 shows a stratigraphic column of the Precambrian units of the FM. Metasedimentary units of the Castner Marble, Mundy Breccia and Lanoria Formation are the oldest exposed units, preserve evidence for an active tectonic margin, and are defined by Seeley (1999) as roof pendants within the Red Bluff Granite (RBGS). The Castner Marble represents the oldest exposed unit of the Franklin Mountains. The unit is composed of a basal metasedimentary succession ~1200m thick (Spencer et al., 2014). Bickford et al. (2000) used zircon ID-TIMS U-Pb to report an age of 1272 ± 5 Ma but stated based on an inherited component, 1260 ± 20 Ma as an estimated age of the two ash beds within the Castner Marble. Pittenger et al. (1994) report similar zircon ages from two hand-picked $^{207}Pb/^{206}Pb$ fractions of 1250 ± 5 Ma and 1267 ± 2 Ma. Pittenger et al. (1994) defined six metamorphosed lithologies on the carbonate ramp. Thomann and Hoffer (1991) described three metamorphic zones based on characteristic mineral assemblages. The unit overlying the Castner Marble is the laterally discontinuous Mundy Breccia

(Bickford et al., 2000). The Mundy Breccia has proposed origins of volcanic agglomerate (Harbour 1960, 1972), weathered basalt lava flow or sill (Harbour, 1960, 1972), basalt flow breccia (McAnulty, 1967), and subaqueous flow breccia (Denison & Hetherington, 1969; Mulder et al., 2017). The Mundy Breccia is considered to be similar in age to the Castner Marble based upon load structures and soft sediment deformation (Pittenger et al., 1994; Bickford et al., 2000) and is unconformably overlain by the Lanoria formation (Spencer et al., 2016).

Seeley (1999) defines the Lanoria formation as a medium to very coarse-grained subarkose and quartz arenite that represent a series of transgressive and regressive pulses with six distinct stratigraphic sequences (LS1-LS6). The Lanoria Formation originated in a tectonically active basin based on paleocurrent indicators and soft sediment deformation Seeley (1999). Lanoria sequences LS1, LS2, LS4, and LS6 all represent marine shelf deposits, LS3 is cut valley fill overlain with tidal deposits, and LS5 is incised valley fill overlain with estuary and deltaic sediments (Seeley, 1999). The host rock of the Lanoria Formation is Proterozoic (Riphean) aged metasedimentary rock; the protoliths are marginal marine sandstone, siltstone and mudstone (Seeley, 1999). Dioritic sills and dikes intrude the latter, LS4 member of the Lanoria Formation. Determinate age of the Lanoria Formation is still up for debate (Mulder et al., 2017; Spencer et al., 2014), but Mulder et al. (2017) note how only 5 of 266 analyses are <1150 Ma and suggest an 1140-1100 Ma correlation with siliciclastic sequences throughout southwest Laurentia.

The 1111 ± 43 Ma Thunderbird Group (Roths, 1993) overlies the Lanoria Formation and contains tuffs, volcanic conglomerates, rhyolitic ignimbrites and porphyritic trachytes (Thomann, 1991). Norman et al. (1987) proposed that the Thunderbird Group is likely the erupted equivalent of the intrusive Red Bluff Granite. Li et al. (2007) noted that the Hazel formation near Van Horn has petrographic affinities to the Thunderbird Group and the RBGS.

The 1086 ± 5 Ma type-A Red Bluff Granitic Complex (Roths, 1993) contains five phases of granitic rocks (Shannon et al., 1997) consisting of intrusive magmatic bodies composed of quartz syenitic sills, granites, leucogranites and pegmatitic dikes (see Table 1). The Precambrian units of the Franklin Mountains are nonconformably overlain by the late Cambrian Bliss Sandstone and Lower Ordovician carbonates (Taylor et al., 2004). Taylor et al. (2004) used trilobite and conodont faunas to distinguish an age for the Bliss Sandstone from the Upper Cambrian and Lower Ordovician. Thomann (1991) reported a diabase intruding all the Precambrian units within the Franklin Mountains, and Harbor (1960) mentioned eight diabase intrusions within the Castner Formation.

Table 1. Stratigraphic column of the Precambrian units of the Franklin Mountains, modified from Bickford et al. (2000), Howard et al. (2015), LeMone (1988), Li et al. (2007), Mulder et al. (2017), Pittenger et al. (1994), Shannon et al. (1997), and Wasserburg et al. (1962).

Geochronologic Units	Chronostratigraphic and Lithostrigraphic Units			Technique
Precambrian (Riphean)	Red Bluff Granitic Sequence	Stage 5 Riebeckite pegmatitic granite	1080 ± 20 Ma[W] 1095 ± 20 Ma[W]	Feldspar Rb-Sr
		Stage 4 Leucogranitic feldspar granite	1124.5 ± 3.5 Ma[H]	U-Pb zircon LA-MC-ICPMS
		Stage 3 Alkali fespar quartz syenite	N/A	N/A
		Stage 2 Alkali feldspar graite	1116.9 ± 8.9 Ma[H] 1110 ± 19 Ma[L] 1120 ± 35 Ma[S] 1040 ± 30 Ma[W]	U-Pb zircon LA-MC-ICPMS U-Pb zircon SHRIMP RG U-Pb zircon TIMS Feldspar Rb-Sr
		Stage 1 Quartz syenite	1122.6 ± 3.7 Ma[H]	U-Pb zircon LA-MC-ICPMS
	Thunderbird Group	Tom Mays Park Fm.	1111± 43 Ma[R]	U-Pb zircon TIMS
		Smugglers Pass Fm.	N/A	N/A
		Coronado Hills Fm.	N/A	N/A
		Lanoria Quartzite	1140-1100 Ma[M]	U-Pb detrital zircon
		Mundy Breccia	N/A	N/A
		Castner Marble	1260 ± 20 Ma[B] 1250 ± 5 Ma[P] 1267 ± 2 Ma[P]	U-Pb zircon TIMS $^{207}Pb/^{206}Pb$ zircon $^{207}Pb/^{206}Pb$ zircon

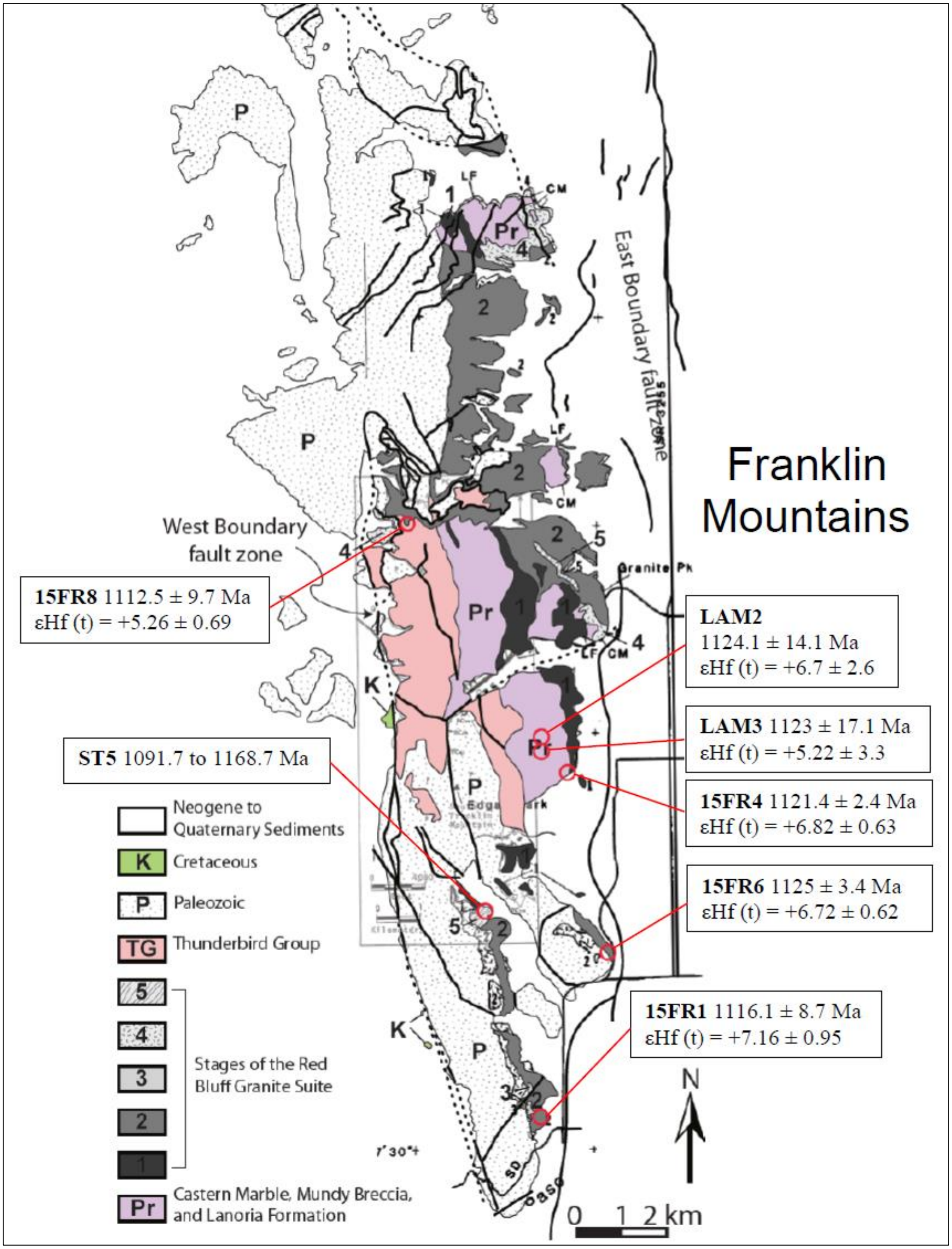


Figure 2. Geologic map showing the reported locations of stages 1-5 of the RBGS. Red circles indicate sample locations.

4. Description of the RBGS Stages and Samples Description

The coarse-grained Red Bluff granite is composed of predominantly quartz, alkali feldspars, riebeckite, micas, and hornblende while zircon, monazite, and apatite are the main accessory minerals.

Stage-1 (S1, see Figure 6) was initially termed microgranite by McAnulty (1967) because quartz is only visible in thin section. S1 is grey to dark grey, holocrystalline, and composed of porphyritic granite to quartz syenite with large euhedral to orbicular microcline glomerophenocrysts (McCutcheon, 1982; Ray, 1982). A fine-grained groundmass of quartz and microcline encloses phenocrysts of orthoclase and quartz (McAnulty, 1967). The more massive sill is granophyric biotite-hornblende, and the smaller sill has large grey to black alkali feldspar crystals in the matrix and is mostly void of mafic minerals. The upper sill has a felsic chill zone, with grain size increasing toward the interior (McCutcheon, 1982). Sample 15FR4 is from S1 of the RBGS; is located on the eastern slopes of the Franklins within Sierra del Puerte Canyon (one valley to the south of Fusselman Canyon/Loop 375). Thin sections from S1 depict granophyric texture from rapid undercooling of quartz and feldspars (see Figure 7a), which is usually due to dehydration within the melt. Phenocrysts from S1 represent mostly interlocking glomerporphyritic aggregates of perthitic microcline, and a groundmass made predominately of quartz. Some exsolution is also apparent.

Stage 2 (S2, see Figure 6) is the most abundant stage by volume, batholitic in proportion, and is highly variable in mineral assemblages. This stage contains veins of hematite, fluorite and is host to the tin deposits. This characteristic red colored granitic stage is holocrystalline, medium to coarse-grained, and contains abundant alkali feldspar, quartz, plagioclase, biotite, and

amphibole (Ray, 1982; Shannon et al., 1997). Samples 15FR1, 15FR6 and 15FR8 are from stage-2 and span from various locations in the Franklin Mountains spanning for more than 13 km (Fig. 2). 15FR1 comes from the eastern slopes of the Franklins near the southern extent of the range in the valley separating Ranger and Comanche Peaks. 15FR6 comes from the east slope of Sugarloaf Mountain. Sugarloaf is the result of a gravity slide of a large fault block that is east of McKelligon Canyon. Diabase intrusions up to 8 m intrude S2 of the RBGS at the Sugarloaf collecting locality as shown in Figure 3. These diabase dikes have no reported age. 15FR8 is from the eastern slopes of Mundy's Gap 1.5 km north, north-west of North Franklin Mountain (Fig. 4). Thin sections from S2 show cumulophyric texture and oscillatory zoning of minerals that represent disequilibrium texture as depicted in Figure 7b. Stage-2 displays euhedral to subhedral oglioclase that occasionally show Carlsbad twinning, albite and pericline twins, biotite and anhedral to subhedral quartz, with minor fluorite and hematite.

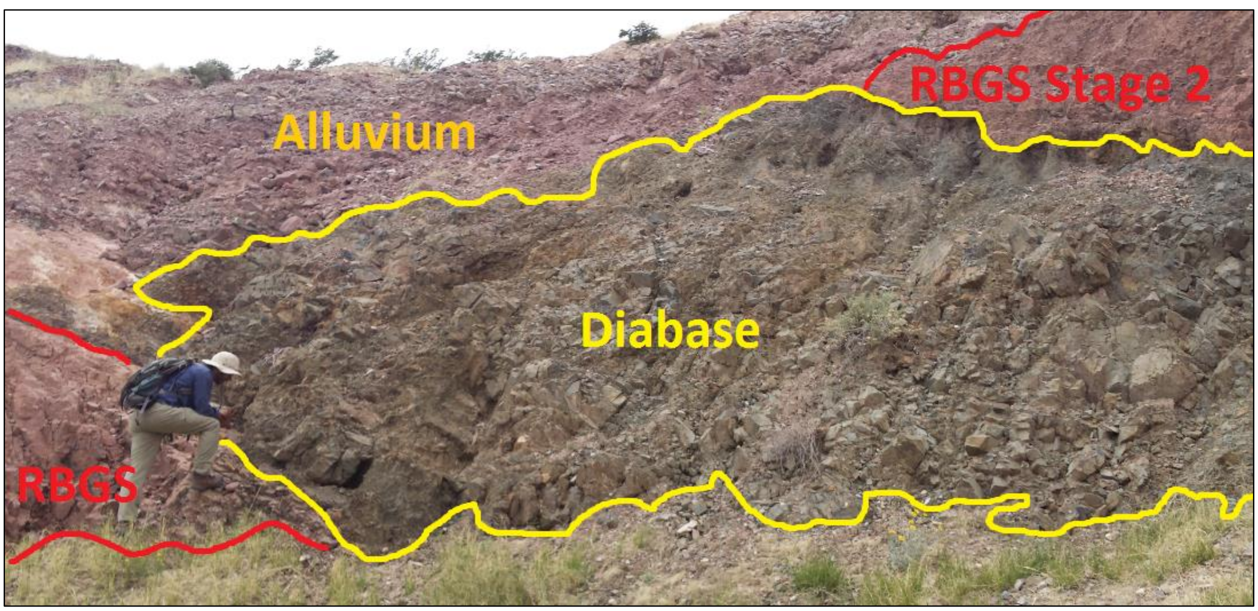


Figure 3. Photograph of RBGS of the Sugarloaf Mountain location showing diabase dike intrusion in stage-2 of RBGS.

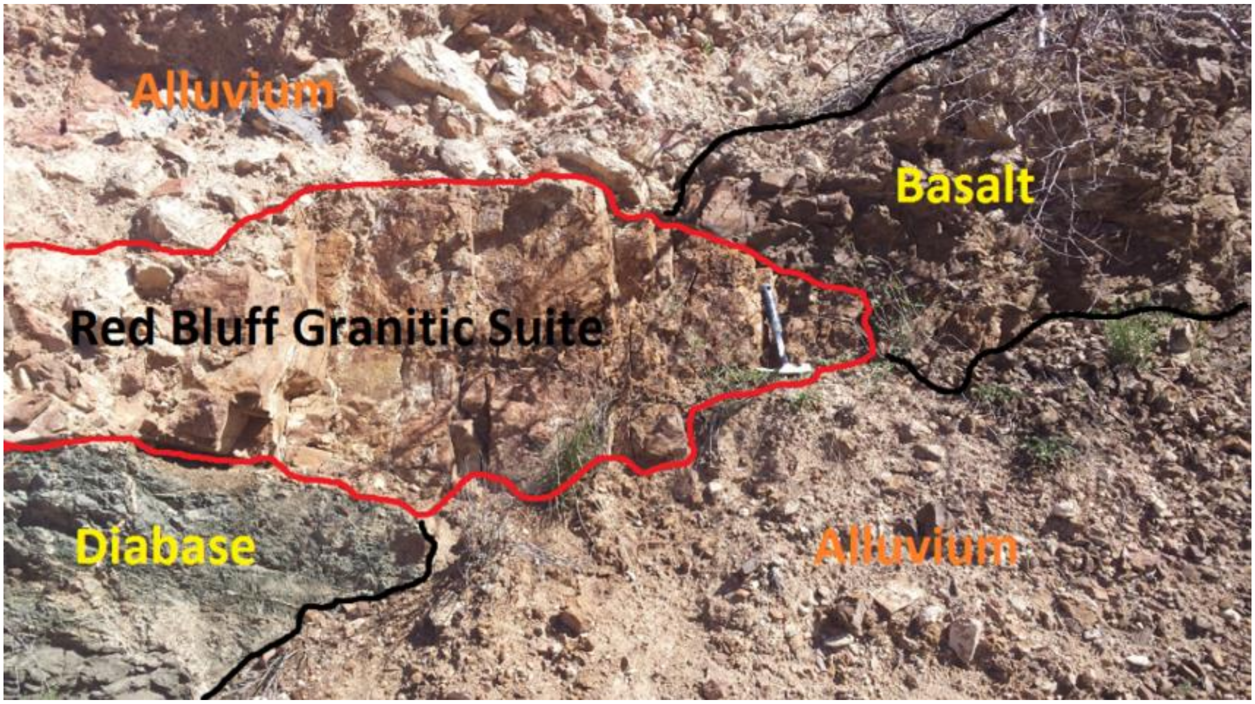


Figure 4. Photograph of an outcrop of RBGS at Mundy's Gap location.

Stage 3 (S3, see Figure 6) is very dark, almost black and is limited to small isolated patches. The biotite-hornblende quartz syenite is holocrystalline, medium to coarse-grained phaneritic (Ray, 1982). Samples contain subhedral alkali feldspar, quartz, biotite, plagioclase, amphibole, and labradorite. Ray (1982) describe this phase as being more coarse-grained than the other granitic phases. Some occurrences of S3, such as within McKelligon canyon display a grain size similar to the other RBGS stages.

Stage 4 (S4, see Figure 6) is a leucocratic, porphyritic, and holocrystalline with a fine-grained matrix (Ray, 1982). The alkali granite occurs in the east-central area of the geologic map, forming an exfoliation dome-like structure named Granite Peak by Hoffer (1972). Fresh samples of the biotite-alkali feldspar granite are light grey to pinkish and occur as dikes in the earlier stages and also intrudes into the overlying Thunderbird Group along the western side of the range (Shannon et al., 1997). The phenocrysts are exclusively light grey to milky white subhedral crystals of alkali feldspar, and the groundmass is composed of quartz and alkali feldspar (Ray,

1982). There is a noticeable absence of mafic minerals. Crystals of biotite and hornblende are present but do not exceed 2% of the modal composition (Ray, 1982).

Stage 5 (S5, see Figure 6) is leucocratic, holocrystalline medium to very coarse-grained phaneritic granite (Ray, 1982). The pegmatite contains black, subhedral, prismatic crystals of mostly riebeckite and minor amounts of black, platy biotite and zircons in a leucocratic matrix consisting of alkali feldspar, quartz, and plagioclase (Ray, 1982). Stage-5 displays strong foliation due to the alignment of the distinctive prismatic riebeckite crystals giving a banding appearance. The dikes of S5 represent the only stage that does not weather a rusty-red color (Shannon et al., 1997). Sample ST5 is located west of the amphitheater in McKelligon Canyon. Thin sections from the S5 show characteristic-blue prismatic arfvedsonite, and cross-hatched microcline, perthitic and well-developed albite twinning. Large, anhedral, highly fractured or very small quartz and K-spar are the most predominate minerals, with subhedral to euhedral oligoclase as shown in Figure 7d.

Sample ST6 is an unreported granitic dike as shown in Figure 6 displays many colors from light brown to orange and weathers to a light grey with black spots; it is a coarse-grained, porphyritic granite with zoned phenocrysts that display dissolved grain boundaries. The granitic dike is comprised primarily of feldspar such as orthoclase with mafic amphibole cores. There are some zoned microcline phenocrysts, with the majority of microcline crystals elongated to show flow orientation. Figure 3 shows the distinction between the granitic dike to the other stages of the RBGS. Thin sections of the granitic dike (Figure 7e) show mostly quartz, plagioclase exsolution in most phenocrysts, arfvedsonite in phenocryst and smaller grains, titanite, and zircon. Seeley (1999) identified six stratigraphic sequences for the Lanoria Formation. The basaltic dikes are ferroan plagioclase-rich peraluminous basaltic dikes that intruded the fourth member of the Lanoria Sequence. The Mesoproterozoic Grenville-aged rocks of the Lanoria Formation within

the Sierra del Puerte Canyon in the Franklin Mountains about 120 m to the Northeast there is a larger N-S oriented mafic dike. This dike is 21 m long with a maximum width of 1.2 m (Fig. 5). The outcrops weather a red-brown (rust) color and a few sections of the larger outcrop displays spheroidal weathering, both of which are exhibited in the RBGS. The two tholeiitic basalt dike-based intrusions are glomeroporphyritic in texture, melanocratic and contain mafic phenocrysts of anorthite and phlogopite. The anorthite phenocrysts exhibit Carlsbad twinning in hand sample and have phenocrysts up to 2 cm and phlogopite phenocrysts up to 1.5 cm (as shown in Figure 7f). Thin sections show opaque anhedral grains that reveal seritization textures and a composition primarily composed of subophitic plagioclase laths with interstitial amphibole (actinolite?) and accessory magnetite. Both mafic dike samples have 49% SiO_2.

Figure 5. Pictures of mafic dikes from the Sierra del Puerte Canyon location showing A) an outcrop from a mafic dike and B) a hand sample.

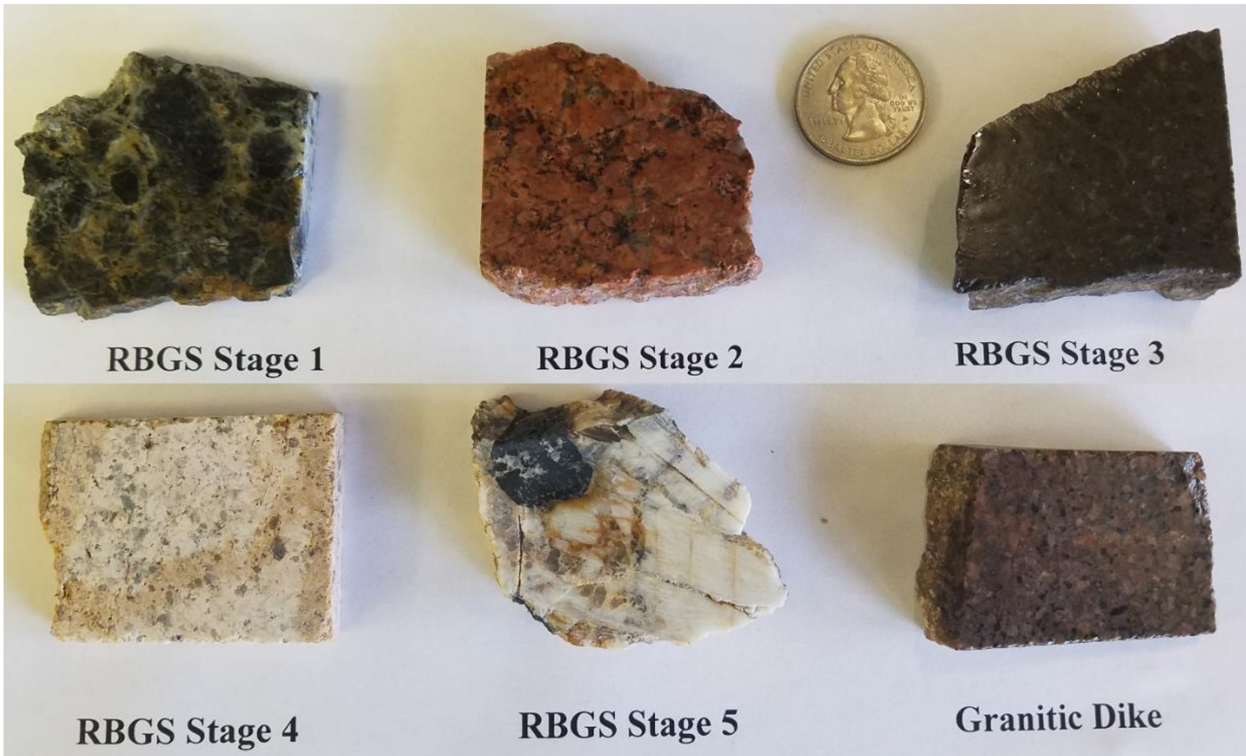


Figure 6. The reported stages 1-5 of the RBGS and an unreported granitic dike.

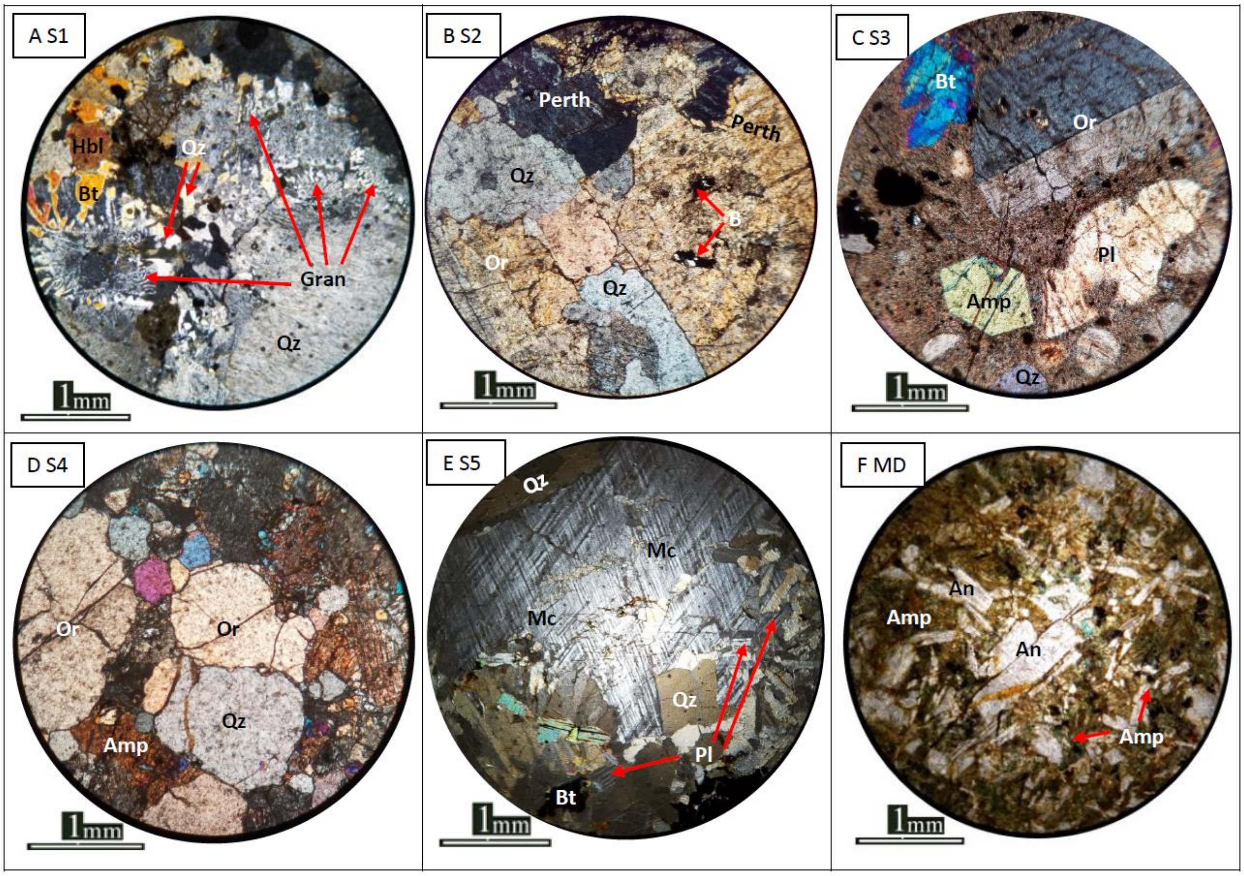


Figure 7. Thin section images of the RBGS stages and the mafic dike. Abbreviations represent An-anorthite, Amp-amphibole, Bt-biotite, Gran-granophyric texture, Hbl-hornblende, Mc-microcline, Or-orthoclase, Perth-perthitic texture, Pl-plagioclase, and Qz-quartz. Sample A) S1 shows granophyric texture, or rapid cooling, B) perthitic, intergrowths of feldspar, C) S3, D) S4 E) pegmatitic S5 with cross-hatched microcline F) mafic dikes showing mostly anorthite and amphibole, with seritization texture.

5. Geochronological Studies of RBGS Magmatism

Nelson (1940) was the first to refer to intrusive rocks in the Franklin Mountains as the Red Bluff Granite. Wasserburg et al. (1962) were the first to provide geochronological constraints on the timing of emplacement. Shannon et al. (1997) extended the stages previously described by Wasserburg et al. (1962) and subdivided the Red Bluff Granitic Suite (RBGS) into five distinct lithologic units, representing five stages of intrusion based on cross-cutting relationships, with S1 being the youngest and S5 the oldest. All descriptions of the RBGS provided in this study are according to the stages described by Shannon et al. (1997). Stages 1a and 1b consist of a meter to

660 m-thick sills in the older Castner Marble and Lanoria Formations respectively (Ray, 1982; Shannon et al., 1997). Table 1 lists previous isotopic analyses for each stage. Roths (1993) reports a U-Pb zircon age of 1086 ± 5 Ma for the RBGS, with an upper intercept age of 1120 ± 35 Ma and a lower intercept of 1144 ± 150 Ma. Copeland and Bowring (1988) provide an age of 1.14 Ga for the RBGS. It is unclear which stages Roths (1993) and Copeland and Bowring (1988) dated. Figure 9 displays a geologic map with stage locations.

6. Grenvillian Magmatism of southwestern Laurentia

The late-stage and post-Grenvillian A-type magmatism in the southwestern USA and northern Mexico has been recorded during three major magmatic pulses, including 1125-1100, 1097-1082, and 1081-1068 Ma. Except Pikes Peak Batholith, all the other ~1.1-1.0 Ga magmatic rocks are emplaced proximal to the Mazatzal-Grenvillian front in further to the south (Fig. 4). Majority of the age data in the following are zircon U-Pb by using instruments like SHRIMP, LA-ICP-MS and TIMS (see Appendix A1). In the following, three magmatic pulses are briefly described.

6.1 1125-1100 Ma

This temporal category marks an extensional period between the compression cycles of the 1190-1140 Ma Shawingian Orogeny and the 1090-1020 Ma Ottawan Orogeny (Rivers, 2008). Stages of the RBGS that have been dated with precise methods such as stages 1, 2, and 4 all reside within this time frame. The synkinematic Grape Creek pluton from the Llano Uplift were dated at 1124-1116 Ma (Barker & Reed, 2010, Howard, 2015). Large postkinematic plutons of the Llano Uplift, many with rapakivi textures, such as the Lone Grove pluton were emplaced at 1101.0 ± 6.4 Ma (Howard, 2015). Examples of the PPB area from the 1125-1100 temporal category an 1106.6 ± 5.3 Ma syenogranite (Howard, 2015) and an 1115 ± 12 Ma quartz syenite from the Lake George

ring complex (Guitreau et al., 2016). Granite and rhyolite boulders in the Hazel formation near Van Horn were dated at 1120 Ma (Spencer et al., 2014) and rhyolites east of El Paso at the Pump Station Hills are ~1100 Ma (Wasserburg et al., 1962). Detrital zircon U-Pb dating revealed the dominant peak age at 1.1 Ga from the Andrews Mountain Member of the Campito Formation in California and Wood Canyon Formation from Caliente Nevada (Howard, 2015). Granites from the Apache Group of southern Arizona and the Unkar Group in the eastern Grand Canyon of Arizona were assigned an age of 1100 Ma (Bickford et al., 2000). Zircon U-Pb TIMS dating from diabase of the Little Dragoon Mountains in southern Arizona yielded an age of 1100 Ma (Silver, 1978). Granite in Santa Margarita of northern Mexico were dated at are 1104 Ma (zircon U-Pb; Anderson & Silver, 2005). U-Pb zircon SHRIMP dating assigned an age of ~1.1 Ga for the Puerto Blanco and El Arpa Formations from Sonora, Mexico (Howard, 2015). Zircon U-Pb SHRIMP dating on diabase dikes in southern New Mexico yielded an age of 1113 Ma in the Burro Mountains (Bright et al., 2014). $^{40}Ar/^{39}Ar$ analyses on biotite and hornblende suggested an age of ~1105 Ma for the granite and rhyolite penetrating the Debaca sequence in New Mexico (Amarante et al., 2005). Bickford et al. (2000) reported an age of 1120 Ma from the Pajarito Mountain in New Mexico. Granite and rhyolite boulders in the Hazel formation near Van Horn were dated at 1120 Ma (Spencer et al., 2014) and Ma rhyolites east of El Paso at the Pump Station Hills are ~1100 Ma (Wasserburg et al., 1962).

6.2 1097-1083 Ma

This temporal category marks the transition from the end of the Ottawan Orogeny into an extensional period (Rivers, 2008). The youngest of the RBGS, S5 is a representative of this temporal category. Three compositional groups from the Llano Uplift are synkinematic irregular plutons, minor 1098-1093 Ma rhyolite dikes and hypersolvus granite, and large postkinematic

plutons with rapakivi textures (Barker & Reed, 2010). Pikes Peak batholith has U-Pb zircon LA-MC-ICPMS ages of a 1089.7 ± 7.2 Ma quartz syenite from the West Creek intrusion and a 1091.4 ± 5.2 Ma monzogranite from the Buffalo Park intrusion (Howard, 2015). U-Pb zircon TIMS of PPB granitic ages are 1085 Ma (Schärer & Allègre, 1982) and 1086 Ma (Smith et al., 1999a). A PPB fayalite-quartz syenite from West Creek is 1085.6 ± 2.5 Ma (Smith et al., 1999a), and the innermost ring complex from PPB has a 1085 ± 5 Ma monzogranite from the Lake George ring complex (Guitreau et al., 2016). The Kingston Range in southern California has U-Pb baddeleyite TIMS ages of 1087 Ma from diabase sills (Heaman and Grotzinger, 1992). U-Pb baddeleyite TIMS ages of diabase sills and dikes include the 1088 Ma from the Hualapai Mountains of western Arizona and 1094 Ma Sierra Ancha of central Arizona (Bright et al., 2014). U-Pb zircon SHRIMP-RG ages are 1087 Ma for the Escuadra Granite and 1083.9 ± 8.6 Ma for the La Lamina block in Mexico (Howard, 2015). U-Pb zircon TIMS ages from the Aibo granites of northern Mexico are 1091 Ma (Anderson & Silver, 2005). Anorthosite and granites from the Sierritas Blancas ~20km southwest of Quitovac, Sonora, Mexico yielded 1095 ± 29, 1086.0 ± 8.7 and 1084.3 ± 6.9 Ma and an anorthosite body ~2 km to the north of Rancho de Santa Margarita, Mexico yielded 1089 ± 13 Ma (Hantsche, 2015).

6.3 1081-1068 Ma

This temporal category resided completely within the Ottawan Orogeny (Rivers, 2008). The anorthositic Three Sisters intrusion is on the edge of the western slopes of the Franklin Mountains; were dated 1068 ± 30 Ma (Li et al., 2007), also igneous xenoliths from Potrillo maar west of El Paso are 1072 Ma (Li et al., 2007). This could correlated with the gravity and magnetic highs discussed later. The Enchanted Rock batholith (ERB) from the Llano Uplift is ~ 1.08 Ga (Reed, 1995; Reed et al., 1995). At PPB, Lake George's outermost ring complex has a 1078 ± 11

Ma monzogranite (Guitreau et al., 2016), and a 1066 ± 10 Ma PPB granite that surrounds the Lake George Ring Complex is also within error (Guitreau et al., 2016). The volcanic ash layer within the Castner Marble is coeval with the ash layer in the Allamoore Formation near Van Horn, Texas (Roths, 1993). The Hazel Formation near Van Horn is the lateral equivalent of the Lanoria formation based on detrital zircon populations, and the Van Horn Formation is 1070 Ma (Spencer et al., 2014). U-Pb zircon TIMS ages from the Aibo granites of northern Mexico include 1075 ± 1.3 Ma (Farmer et al., 2005), and U-Pb zircon SHRIMP of 1080 Ma (Iriondo et al., 2003). The Las Escuadra granite from northern Mexico is 1076 Ma (Amato et al., 2009). A rapakivi granite in the Little Hatchet Mountains of southern New Mexico has a U-Pb Concordia age of 1077 ± 4 Ma (Amato & Mack, 2012). Drill core of A-type granites at the Abilene gravity minimum (AGM) near Albany Texas are 1078 ± 23 Ma, a mafic sill in the Texas Panhandle is 1081 ± 8.3 Ma (Li et al., 2007). Diabase from the Pinaleño Mountains of southern Arizona and Salt River Canyon in central Arizona are 1080 Ma (Bright et al., 2014). Bright et al. (2014) cite Shastri et al. (1991) that 1080 Ma diabase is from Peacock Mountains in northern Arizona. Orthopyroxenite from drill holes as deep as 5 km in the central basin of west Texas have U-Pb ages of 1075 and 1078 Ma (Keller et al., 1989), which Li et al. (2007) described as the Pecos mafic intrusive complex (PMIC).

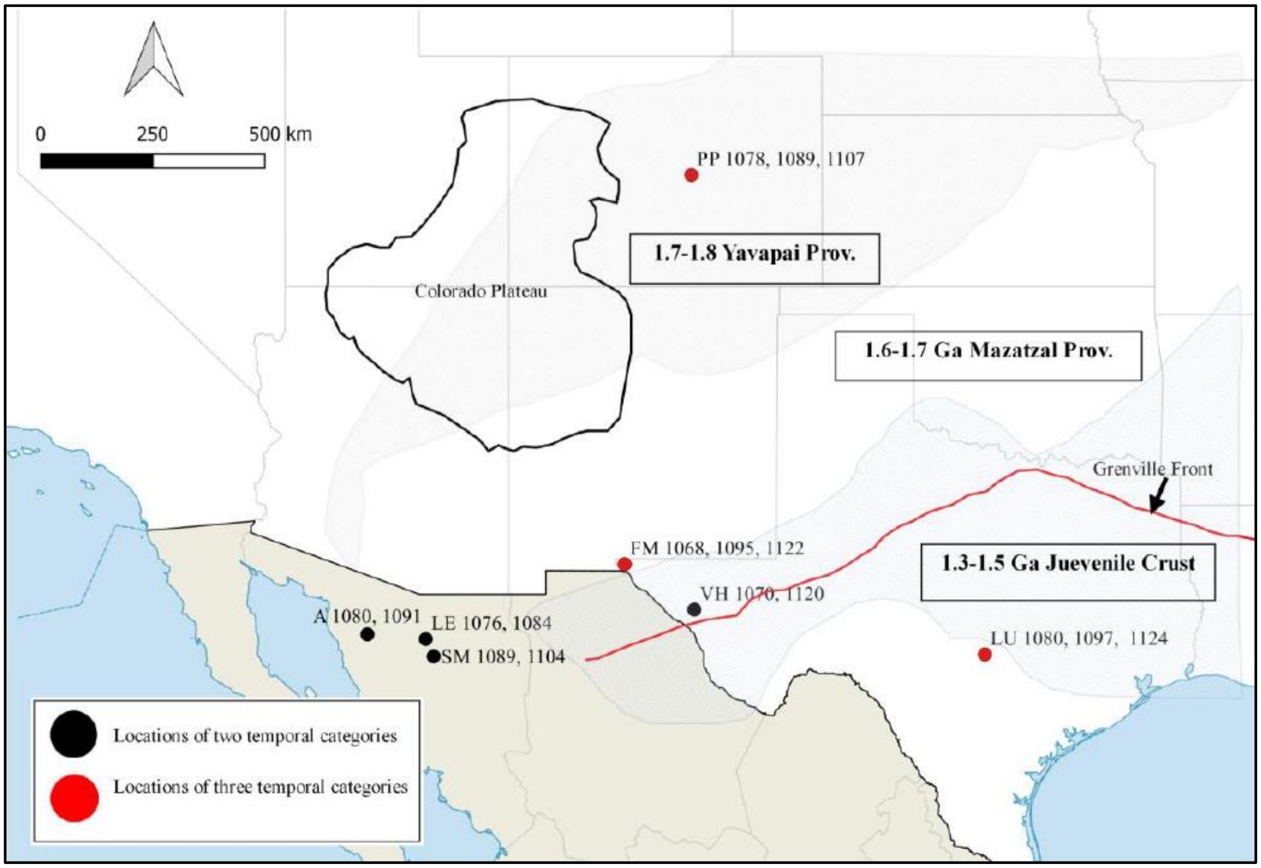


Figure 8. Locations for three Grenville temporal categories. Ages are shown in Ma. Modified from (A)-Amato et al. (2009), (A/S)-Anderson & Silver (2005), (B)-Bright et al. (2014), (B/R)-Barker & Reed (2010), (G)-Guitreau et al. (2016), (H)-Howard (2013), (Ha)-Hantsche (2015), (L)-Li et al. (2007), (R)-Reed et al. (1995), (S)-Spencer et al. (2014), and (W)-Wasserburg (1962).

7. Present Understanding for the Magmatic Evolution of Southwestern Laurentia

7.1 Franklin, Llano, and Little Hatchet Mountains

In the Franklin Mountains and Llano uplift all three magmatic pulses have been recorded (Fig. 8). Geochemically, the granitoids in Franklin granites have been classified as the Na-rich, anorogenic and rift-related A-type magmatic rocks (e.g., Anderson, 1983; Norman et al., 1987; Shannon et al., 1997; Smith et al., 1997). Geochemical and petrological data suggest that the RBGS was produced by the fractionation of mantle-derived basalt (Smith et al., 1997). Using log Rb versus Zr contents in the RBGS and models for crystallization and partial melting, Smith et al.

(1997) concluded partial melting of tonalitic compositions could not produce Zr content of the RBGS, nor could it explain compositional trends. Norman et al. (1987) suggested that the basaltic rocks from the FM are similar to island arc-related basalts based on low Ti, Zr, and Ta and high La/Ta and Th/Ta ratios. The mildly radiogenic Sm-Nd isotopic composition (i.e., 2.5 to +3.8) of basalt and granites from the Van Horn and Franklin suggest the mantle-related sources (Norman et al., 1987). This is also supported by the mantle-like Pb isotopes composition of Franklin granites (Smith et al., 1997). It is interesting to note that FM have both have gravity and magnetic highs (Adams & Keller, 1994) which are potentially resulted by a mafic body in the subsurface (Hadi, 1991). Adams and Keller (1994) mention the gravity high has a north-south orientation, extends 50 km from northern Mexico, and extends beyond the Franklin Mountain fault block. Li et al. (2007) suggested the same conclusion due to the distance from the anorthosite of the Three Sisters Intrusion to the xenoliths of the Kilbourne Hole maar. All five stages contain initial Pb isotopic compositions relative to mantle source(s). Oxygen isotopic data suggest the assimilation of crustal rocks up to 20% only if the crustal component were similar to 1.1 Ga depleted mantle (Smith et al., 1997; Shannon et al., 1997). In contrast, typical subduction-related geochemical composition of Llano plutons suggest their emplaced proximal to the continental margin of Laurentia (Mosher 1998). Smith et al. (1997) suggested that the ERB represent anatectic melts derived from crustal sources due to the large volume of granite and lack of the associated mafic rocks. Smith and Wark (1992) interpreted the ERB as the mixing of which two or three sources, specifically a magma was injected and cooled into a partially molten host.

7.2 Pikes Peak Batholith and Wood Canyon Formation

The Lake George ring complex is series of seven alkali intrusions within Pikes Peak Batholith (Guitreau et al., 2016). Like FM and LU, the ring complex recorded the all three

magmatic episodes (Figure 8) Smith et al. (1999b) describe how magma mixing played a role in the compositional diversity of PPB due to the close emplacement in space and time of at least two petrogenetically different granites. This was later confirmed by Chastain and Noblett (1994) through intertwined textures and geochemical exchanges between units. Geochemically, PPB show remarkable similarities to the FM (Smith et al., 1999a). Smith et al. (1999a) interpret the sodic syenites and granites as fractionation products of mantle-source basaltic magmas with minimal crustal involvement that were previously affected by subduction-related processes and potassic granites derived from crustal melts (Smith et al., 1999b). Smith (1999a) points out the Nb and Ta depletions are similar to subduction-related basalts. The RBGS and PPB both plot "within-plate" due to high concentrations of Nb and Y (Smith 1997). REE abundances for the dominant volumes of the ERB, PPB, and RBGS display a distinctly similar shape when normalized to a chondritic reservoir (Smith, 1997).

7.3 Grenville-Related Magmatism in northern Mexico

The Caborcan crust which contains the 1075 ± 1.3 Aibo granite is from anataxis of a local Precambrian basement (Farmer et al., 2005). Numerous rocks from northern Mexico recorded the latest magmatic event. Hantsche (2015) interpret that the the 1.086 ± 0.02 Ga anorthosite-charnockite-mangerite-granite suite in Sonora, Mexico to have crystallized from a melt with a significant component of Paleoproterozoic Yavapai/Mazatzal Province crust.

The dominant magmatism is recorded around 1100 Ma at Pikes Peak, Arizona, and Caborca; whereas, Llano Uplift and the Franklin Mountains also recorded the magmatism as old as 1140 Ma (Fig. 9).

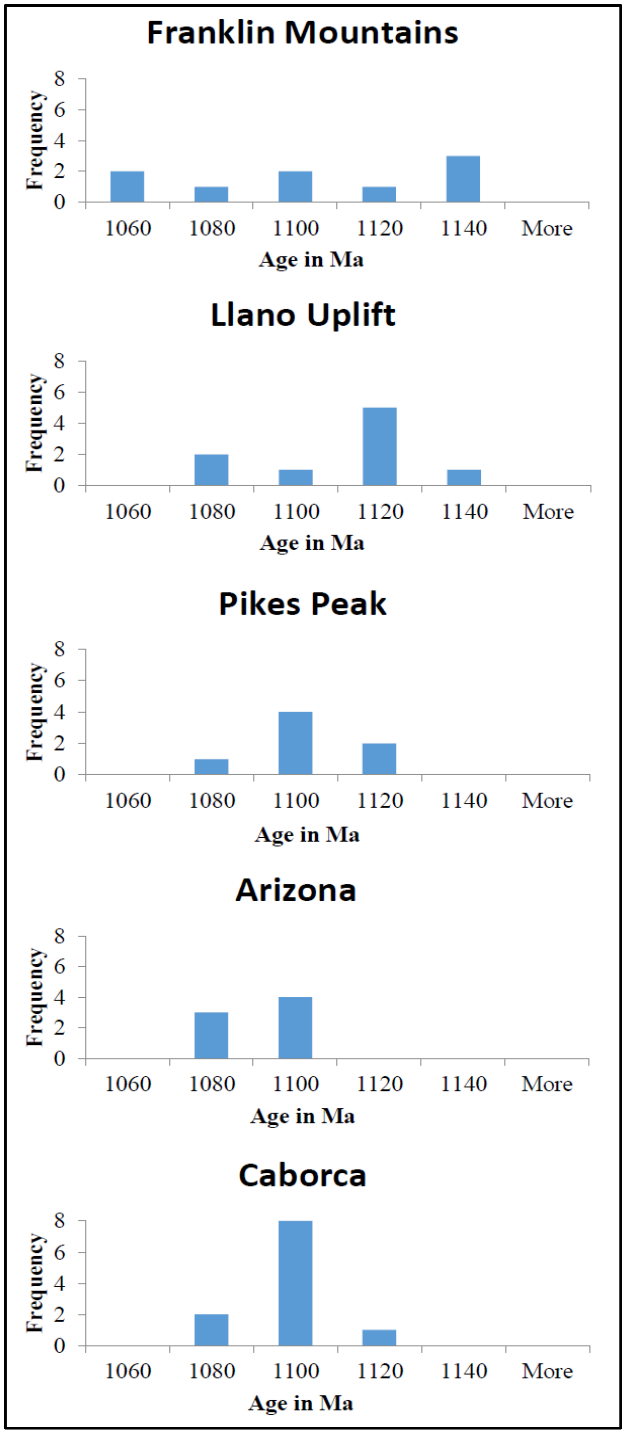


Figure 9. Late-stage magmatic pulses in the Franklin Mountains, Pikes Peak, Llano Uplift, Caborca, and Arizona.

8. Analytical Methods

Whole-rock geochemical analyses were performed by Activation Laboratories (ACT Labs) in Ancaster, Ontario, Canada, using methods described on their website: http://www.actlabs.com/. Lithium Metaborate/Tetraborate Fusion–ICP and Lithium Metaborate/ Tetraborate Fusion–ICP/MS determined major elements, trace elements, and rare earth elements (REE). Laser ablation– multicollector-inductively coupled plasma mass spectrometry (LA–MC–ICP–MS) from the LaserChron laboratory, the University of Arizona performed the zircon U–Pb and zircon Hf isotopic measurements. The analytical methods for zircon U–Pb and Hf isotopic measurements are fully described in Gehrels et al. (2008), Gehrels and Pecha (2014), and Cecil et al. (2011). Appendices A.2-A.3 detail the methods used.

9. Results

9.1 Whole Rock Geochemistry

The SiO_2 content of the granitic rocks varies from 61 to 77% and for the mafic dikes is ~49%. The K2O+Na2O of granitic samples vary from 9 to 11%. On the total alkali-silica diagram, majority of the samples plot within the akaline granite field however, peralkaline stages 1 and 2 plot within the syenite and quartz monzonite fields, respectively, and the mafic dikes plot as gabbro (Fig.10a). Unsurprisingly, all the rocks plots along the FeO-alkali line on the AFM diagram (Fig. 10b). Stages 2, 3, and 5 are relatively more enriched in Iron and stages 1 and 4 show peralkaline character. The basaltic dikes plots within the tholeiite field (Fig. 10b). The data within the AFM diagram support the suggestion by Ray (1982) that stages 2-4 are from a single parent magma and represent vertically differentiated granitic phases based on their relative positions within the magma chamber, with the leucogranite (S4) at the top, the quartz syenite (S3) at the bottom and S2 in-between. All the samples plot within the high-K calc-alkaline to shoshonitic series on the

K2O vs SiO2 plot (Fig.10c). Stages 1, 2, and 3 plot either within or closer to the shoshonitic series. Stage 4 plots towards the upper limit of the high-K calc-alkaline series, and S5 pegmatite falls within the high-K calc-alkaline to the calc-alkaline series. On the QAP plot, all the samples plot either within the granite or alkali feldspar granite field.

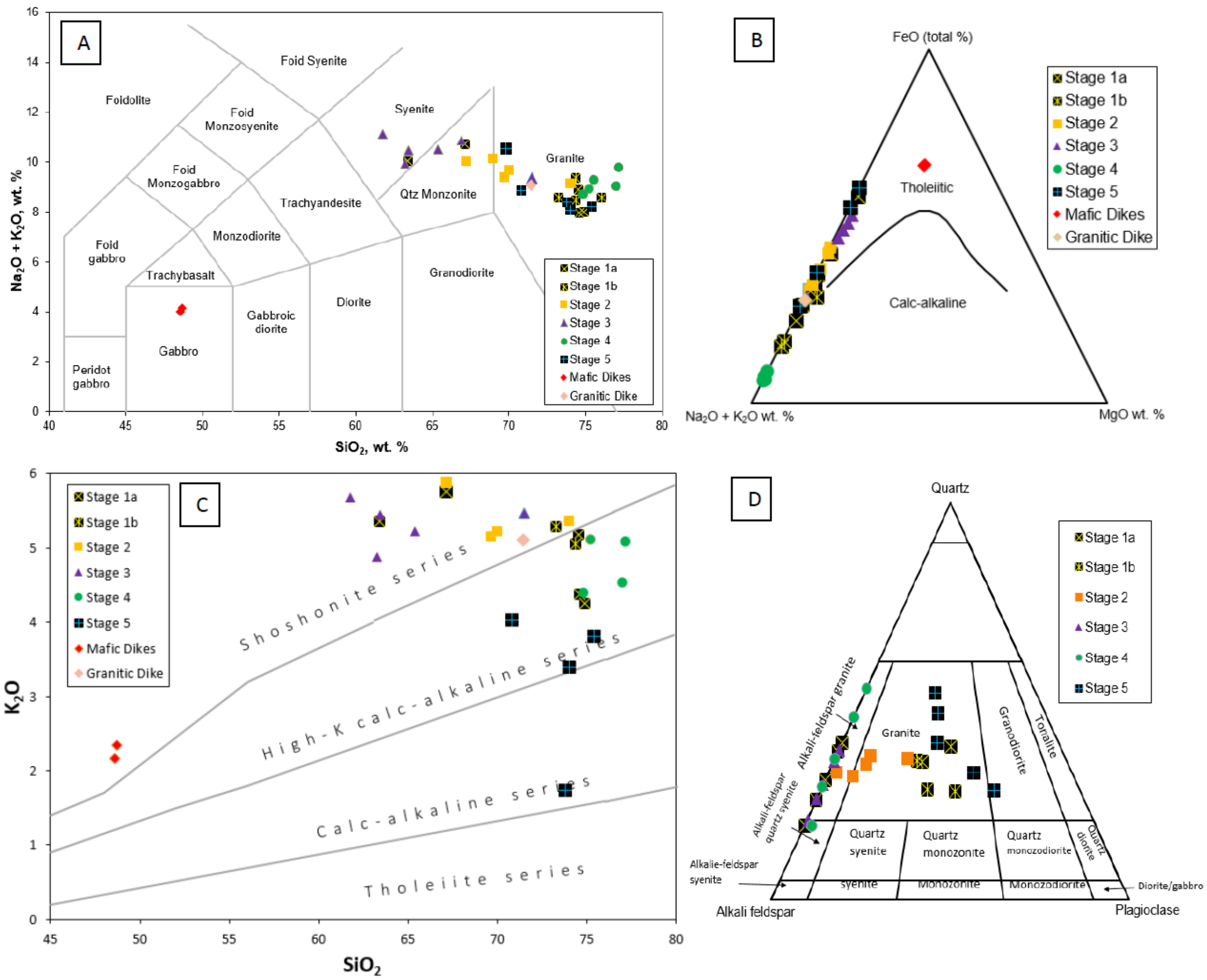


Figure 10. Plots for all RBGS samples showing A) total alkali-silica plot after Middlemost (1985), B) the fields displayed on the AFM diagram for calc-alkaline and tholeiitic series are from Irvine and Baragar (1971), C) K_2O vs. SiO_2 variation diagram after Ewart et al. (1983), and D) QAP diagram according to Streckeisen (1967). Previous data from RBGS is from McCutcheon (1982), Ray (1982), and Shannon et al. (1997).

All the granite samples showed enrichment in HFSE, a typical characteristic of alkaline A-type granites (Fig. 11a, b). Numerous plots show S5 with a different geochemistry than the other

stages. All stages of the RBGS including the granitic dike, and the mafic dikes plot as A2-type anorogenic granites. This is consistent with the previous interpretation using discrimination plot of Sc/Nb vs. Y/Nb (Shannon et al., 1997), except S4 samples which plots both as A1 and A2.

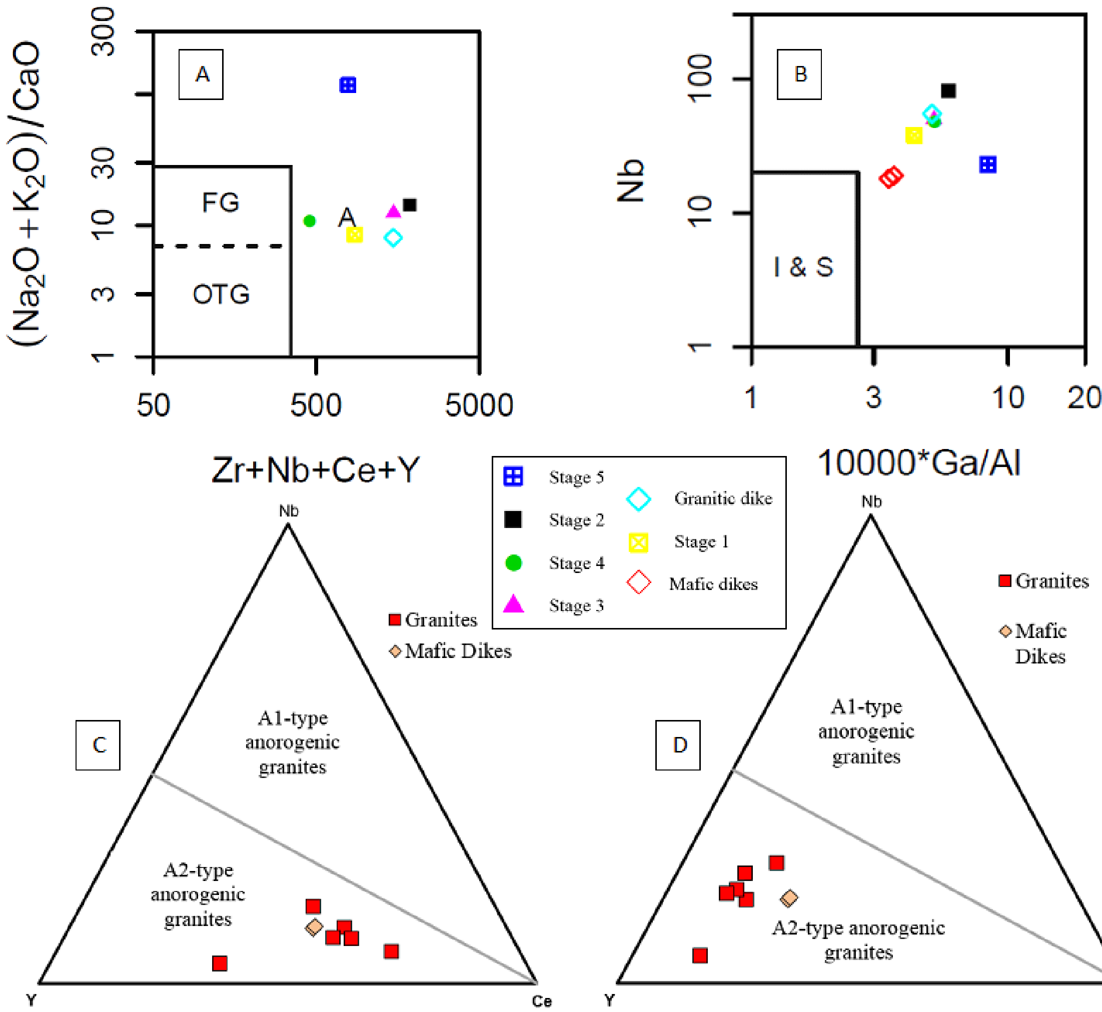


Figure 11. A-B differentiate A-type granites (by Whalen et al., 1987) and B-C discriminate A1 & A2 anorogenic granites (Eby, 1992).

The tectonic discrimination diagram shown in Figure 12a by Pearce et al. (1984) shows the granitic dike, the mafic dikes, and RBGS stages 1 to 4 all plot within plate, the only exception is S5. Refined tectonic discrimination plots by Pearce et al. (1984) shown in Figure 12b place all the granitic and mafic dikes and the RBGS stages 1 to 4 between ocean-ridge granites and within-plate granites. All these units plot within the section of the diagram for the diagram for the upper

boundary for ocean ridge granites from anomalous ridge segments. The only exception is S5. Figure 12c shows a magmatic discrimination plot after Hernández-Pineda et al. (2011).

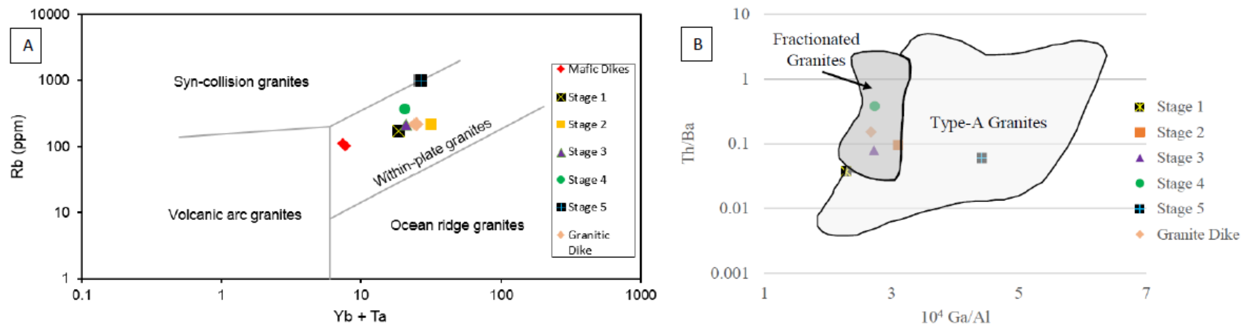


Figure 12. Discrimination plot A is after Pearce et al. (1984) and plot B is from Hernández-Pineda et al. (2011).

Figures 13a-d show distinct troughs in Ba, Nb, Sr, P, Ti, and Eu. Cesium enrichment in basalts (as shown in Figures 13a-c) is due to late-stage hydrothermal alteration as evident by the partial replacement of plagioclase by epidote, and the Eu anomaly suggests the fractionation from a basaltic magma. Figures 13b-d show that P is missing troughs for stages 4 and 5, and Ti is much lower in stages 4 and 5. Flatter HREE patterns might suggest magma generated at the garnet stability field or garnet sequester out of a magma source, but Shannon et al. (1997) mentioned chondrite-normalized REE have shallow negative slopes and mantle-normalized multielemental diagrams have a similarity of elemental ratios. There is a slight enrichment in LREE. REE plots showed little variation when normalized to chondrites (not shown). Multielement patterns of our data show REE enrichment is higher normalized to chondrites and a primitive mantle than OIB (Figures 13b-d), and both the RBGS and mafic dikes display many elements equal to or nearly equal to OIB (Figure 13c). Several elements from the mafic dikes plot directly equal to OIB, such as Th, U, Ce, Pr, and Zr. Shannon et al. (1997) point out a similar trend that mantle-normalized multielement patterns are similar to OIB, and that lower Ta and Nb relative to adjacent elements are typical of island arc basalts and could potentially mean mantle-derived source(s). Numerical

models of inefficient fractional crystallization produced by Shannon et al. (1997) showed the cause of chemical variation from stages 1-4 and concluded partial melting of crustal rocks is not compatible with element concentration or trends in the RBGS.

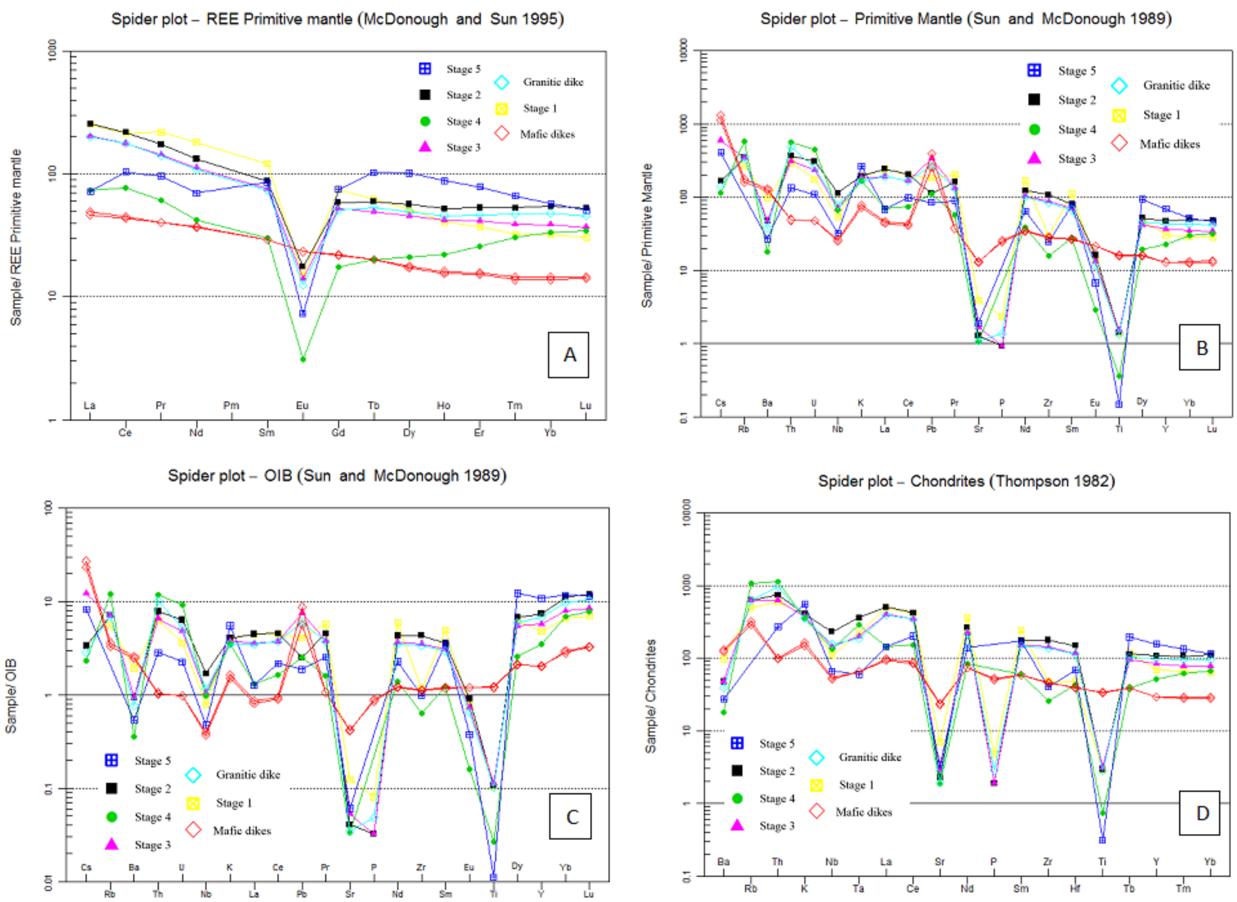


Figure 13. Spider plots normalized to a primitive mantle, OIB, and chondrites and REE plot normalized to a primitive mantle.

9.2 Zircon Morphology

Zircons from the RBGS are 100 to 500 microns in length (as shown in Figure 14). The zircons are typically euhedral and elongate, but occasionally subhedral. CL images show occasional inclusions within zircons of mafic dikes and zircons of the RBGS to be inclusion rich. Stage-2 zircons of the RBGS show convoluted zoning textures most notably in the interior of the grains and contain antecrystic inheritance, mostly from 1130-1140 Ma; one sample has xenocrystic rim inheritance. Stage-1 has xenocrystic rims of 1225 and 1147 Ma. Stage-5 has xenocrystic inheritance of 1168 Ma. Zircons from samples LAM2 and LAM3 are from mafic dikes, are 100 to 200 microns in length, have small length to width ratios, are mostly subhedral, show strong oscillated zoning, numerous inclusions, and contain xenocrystic rims of 1164 and 1137 Ma and a xenocrystic core of 1260 Ma (as shown in Figures 15a-b).

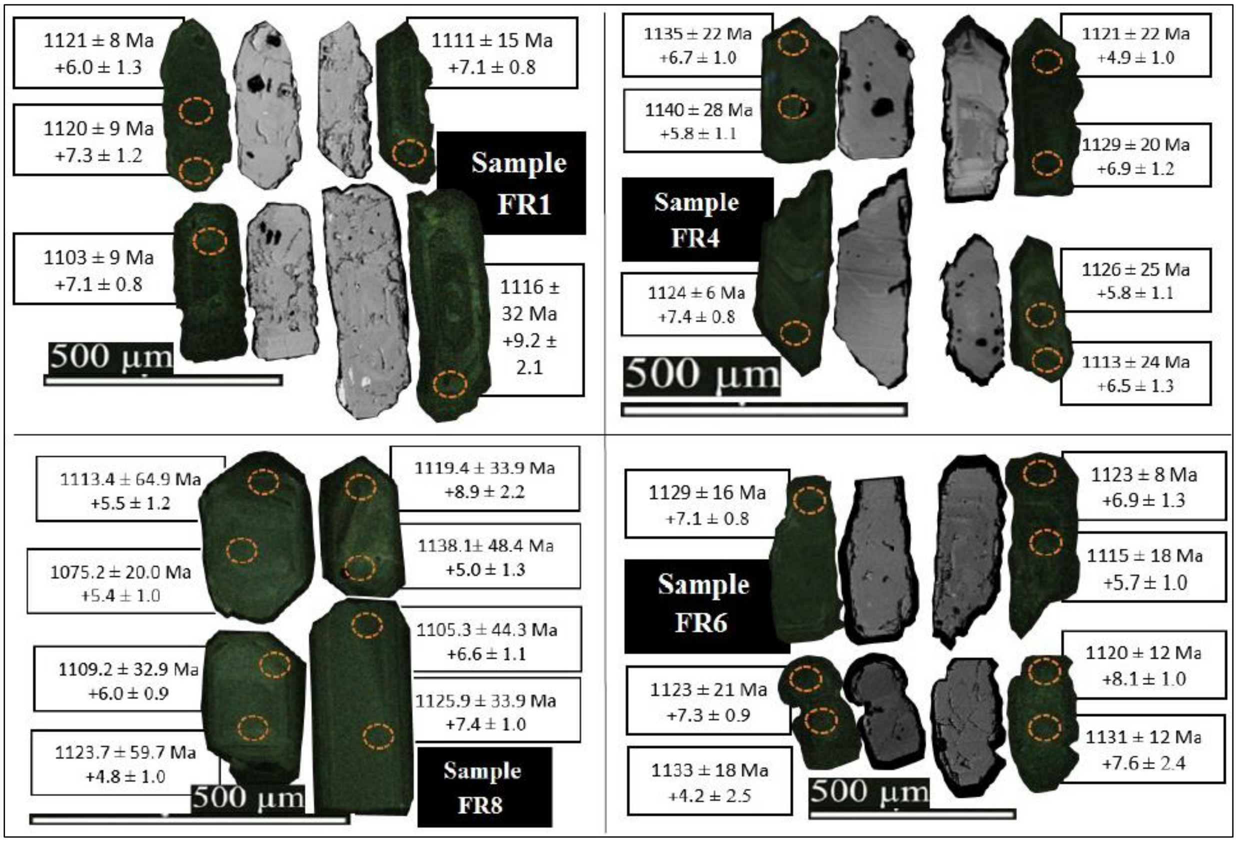


Figure 14. CL and BS images of zircons from RBGS showing samples FR1, FR4, FR6, and FR8. Orange circles indicate U-Pb ages with uncertainties and εHf (t); whereas, yellow circles show only U-Pb ages with uncertainties.

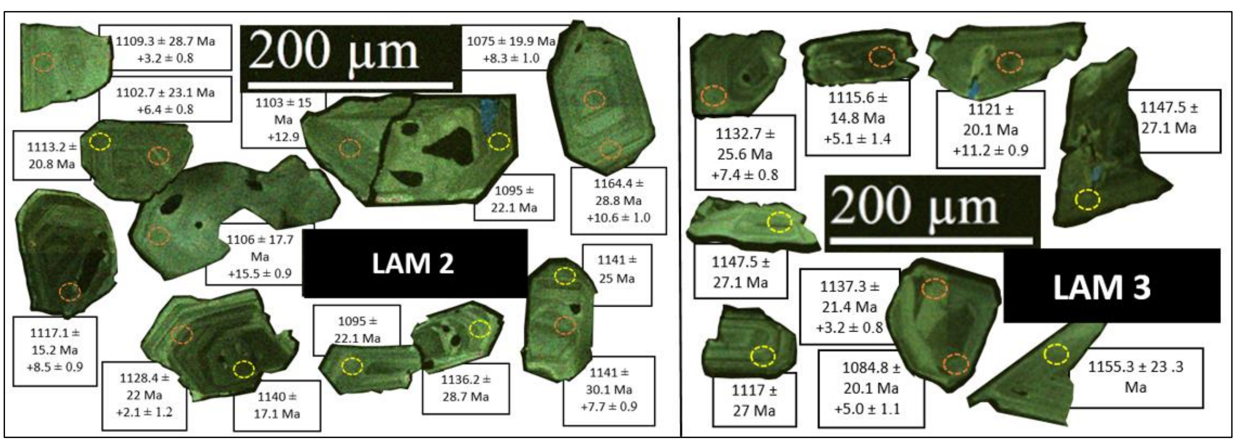


Figure 15. CL images of zircons from mafic dike showing A) sample LAM2 and B) sample LAM3. Orange circles indicate U-Pb ages with uncertainties and εHf (t); whereas, yellow circles show only U-Pb ages with uncertainties.

9.3 LA-ICP-MS U-Pb Geochronology

Zircons of the RBGS are shown in Figure 14. Zircons obtained from sample FR4 are from S1 of the RBGS (quartz syenite), 20 analyses yielded ages from 1108.1 ± 15.7 Ma to 1148.0 ± 25.1 Ma. Analyses range from 0.3% to 4.1% discordant with a Concordia age of 1121.3 ± 2.9 Ma (MSWD = 0.0063) and a weighted mean age of 1121.4 ± 2.4 Ma (MSWD = 1.4, n = 20). Samples FR1, FR6, and FR8 are from S2 of the RBGS (granite). Six analyses of sample FR1 yielded ages from 1103.7 ± 8.9 Ma to 1130.4 ±16.5 Ma. Zircon grains are mostly discordant; analyses range from 0.4% to 12.2% discordant with an upper intercept age of 1123.1 +9.9/-9.0 Ma (MSWD = 0.95) and a weighted mean age of 1116.1 ± 8.7 Ma (MSWD = 0.66). Sixteen analyses from sample FR6 yielded ages from 1114.8 ± 17.7 Ma to 1138.4 ± 15.1 Ma. Zircon grains are generally discordant; analyses range from 0.1% to 9.4% discordant with an upper intercept age of 1124.5 ± 3.1 Ma (MSWD = 0.65) and a weighted mean age of 1125 ± 3.4 Ma (MSWD = 0.72). The weighted mean age of samples FR1 and FR6 are within error of the upper intercept ages. Twenty-five analyses from sample FR8 yielded ages from 1067.9 ± 83.2 Ma to 1138.1 ± 48.4 Ma. Analyses range from 0.1% to 4.0% discordant with a Concordia age of 1118.4 ± 5.4 Ma (MSWD = 0.42) and a weighted mean age of 1112.5 ± 9.7 Ma (MSWD = 0.54). There were very few zircons extracted from sample ST5; three analyses yielded ages from 1091.7 to 1168.7 Ma.

Zircons from the basaltic dikes are shown Figures 15a-b. Thirteen analyses of sample LAM2 yielded ages from 1095.0 ± 22.1 to 1164.4 ± 28.8 Ma. Analyses range from 0.3% to 5.5% discordant with an upper intercept age of 1127 +19/-16 Ma (MSWD = 0.96) and a weighted mean age of 1124.1 ± 14.1 Ma (MSWD = 0.82). One zircon had a core with an age of 1260.4 ± 31.9 with a 16.4% discordance was excluded from the reported age calculations. Seven analyses from sample LAM3 yielded ages from 1084.8 ± 20.1 Ma to 1155.3 ± 23.3 Ma. Analyses range from

0.1% to 6.1% discordant with an upper intercept age of 1120 ± 20 Ma (MSWD = 0.63) and a weighted mean age of 1123 ± 17.1 Ma (MSWD = 1.2). The weighted mean ages of LAM2 and LAM3 are within error of the upper intercept ages. Two zircons had ages of 2303.1 ± 14.6 Ma and 2484.7 ± 17.3 Ma with discordances of 5.5% and 2.5% and were excluded from the reported age calculations.

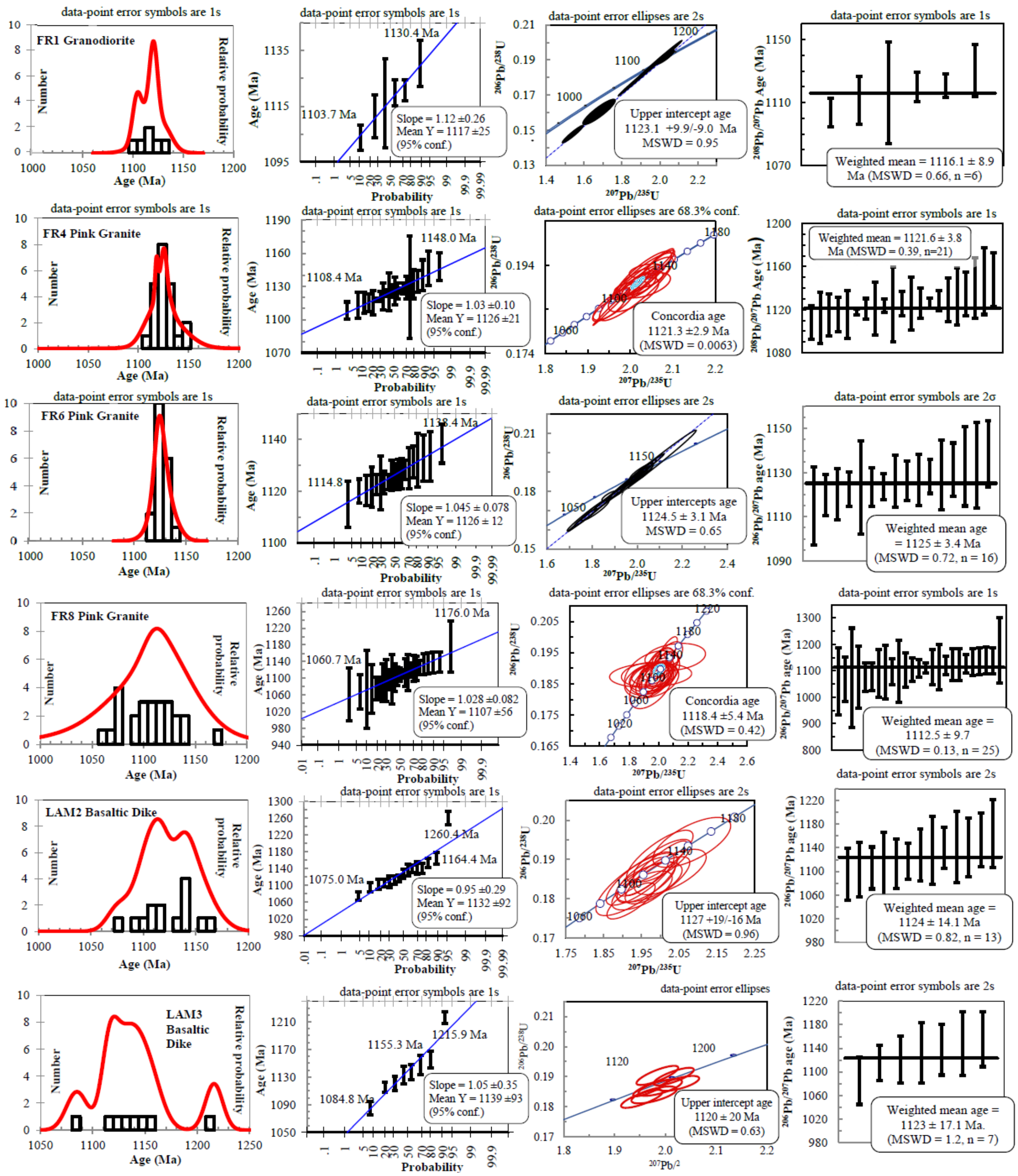


Figure 16. Concordia age, probability density plots, and weighted mean age plots for zircons from the studied granitic and basaltic rocks. Error ellipses and calculated ages are at the 95% confidence level. MSWD—mean square of weighted deviates. Dashed error ellipses in Concordia plots and ages shown as black in weighted mean plots were excluded in age calculations.

9.4 LA-ICP-MS Hf Isotopic Data

Weighted mean Hf isotopic compositions are shown in Figure 17. Hafnium isotopic data from sample FR4 resulted in a range of εHf (0) values from -19.8 to -14.1. Uncertainties range from 0.7 to 2.0. Epsilon Hf(T) values range from +4.9 to +7.6 and a weighted mean εHf (t) of +6.82 ± 0.63 (MSWD = 1.3, n=14). Sample FR1 resulted in a range of εHf (0) values from -18.4 to -12.0. Uncertainties range from 0.8 to 2.1. Epsilon Hf(T) values range from +4.6 to +9.2 and a mean weighted εHf (t) of +7.16 ± 0.95 (MSWD = 1.00, n=6). The εHf (0) values from sample FR6 range from -18.1 to -12.7. Uncertainties range from 0.8 to 3.2. Epsilon Hf(T) values range from +3.9 to +7.6 and a mean weighted εHf (t) of +6.72 ± 0.62 (MSWD = 0.58, n=13). The εHf (0) values from sample FR8 range from -20.0 to -15.4. Uncertainties range from 0.8 to 2.2. Epsilon Hf(t) values range from +3.3 to +8.9 and a mean weighted εHf (t) of +5.26 ± 0.69 (MSWD = 1.5, n=15).Hafnium isotopic data from sample LAM2 resulted in a range of εHf (0) values from -22.3 to -14.5, with the exception of one sample with an εHf (0) value of -8.8. Uncertainties range from 0.8 to 1.3. Epsilon Hf(T) values range from +2.1 to +12.9 and a mean weighted εHf (t) of +6.7 ± 2.6 (MSWD=9.4, n=7). The εHf (0) values from sample LAM3 range from -21.6 to -13.2. Uncertainties range from 0.8 to 1.4. Epsilon Hf (t) values range from +3.2 to 11.2 and a mean weighted εHf (t) of +5.2 ± 3.3 (MSWD=4.9, n=4).

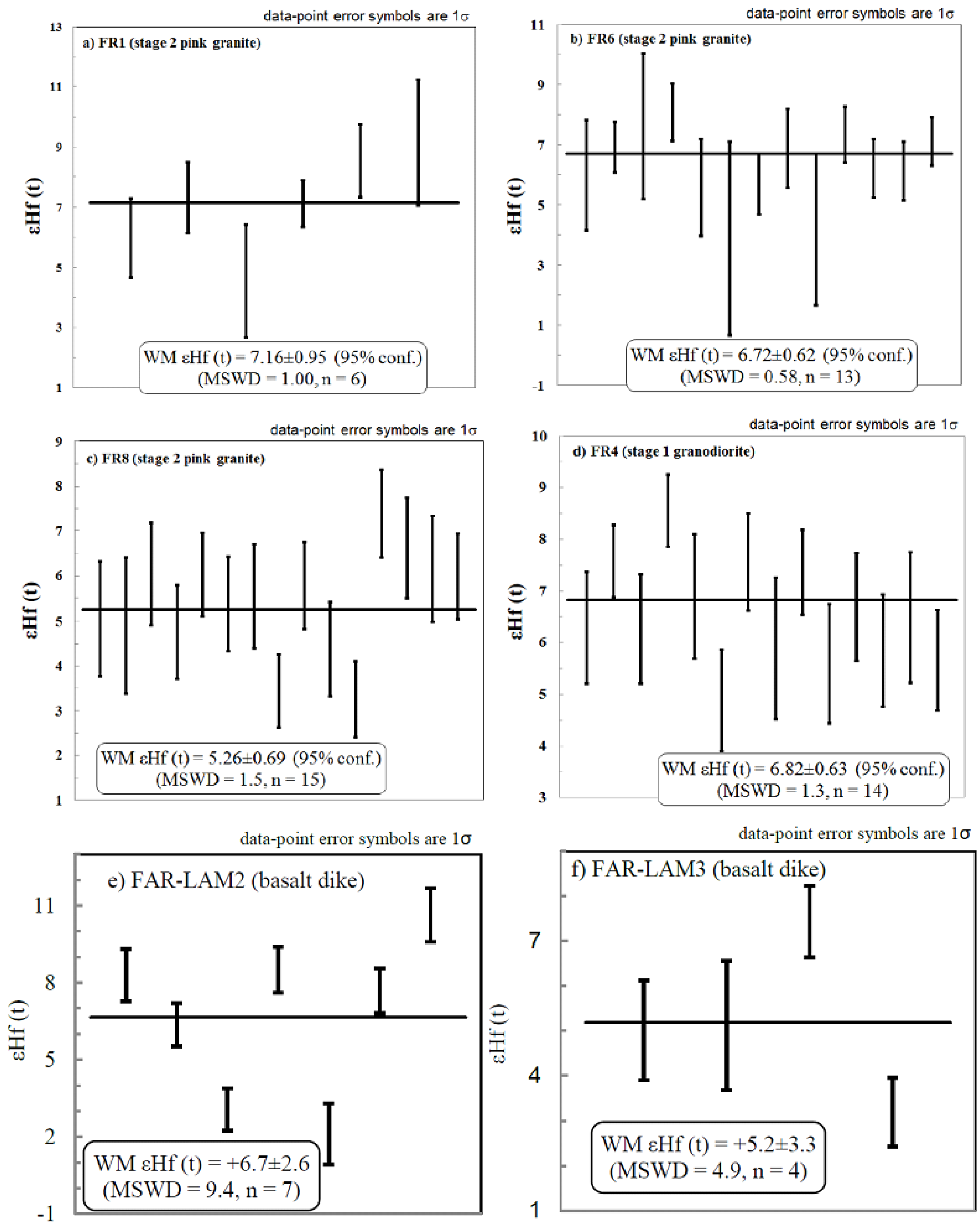


Figure 17. Weighted mean zircon Hf isotopic composition of studied samples.

Table 2. Sample summary table; note: MSWD-mean square of weighted deviates and n.d-no data.

Sample	Rock Unit	location	QAP	U-Pb zircon age (Ma) (MSWD, n)	inheritance	Fe number	Alkalinity SiO2 vs K2O	Tectonic setting (Yb + Ta) vs Rb	SiO_2	Zircon initial εHf(t) (MSWD, n)
15FR4	RBGS Stage 1	Sierra del Puerte Canyon	1a-Alkali-feldspar granite 1b-Granite	1121.4 ± 2.4 Ma (1.4, 20)	Xenocrystic (1147 and 1225 Ma)	.957	Shoshonite	Within Plate	67.13	+6.82 ± 0.63 (MSWD = 1.3, 14)
15FR1	RBGS Stage 2	Ranger Peak	Granite	1116.1 ± 8.7 Ma (0.66, 6)	Antecrystic (1130 Ma)	.981	Shoshonite	Within Plate	67.15	+7.16 ± 0.95 (MSWD = 1.0, 6)
15FR6	RBGS Stage 2	Sugarloaf Mountain	Granite	1125 ± 3.4 Ma (0.72, 16)	Antecrystic (1138 Ma)	n.d.	n.d.	n.d.	n.d.	+6.72 ± 0.62 (MSWD = 0.58, 16)
15FR8	RBGS Stage 2	Mundy's Gap	Granite	1112.5 ± 9.7 Ma (0.54, 25)	Xenocrystic (1178 Ma)	n.d.	n.d.	n.d.	n.d.	+5.26 ± 0.69 (MSWD = 1.5, 15)
ST5	RBGS Stage 5	McKelligon Canyon	Granite	1091.7 to 1168.7	Xenocrystic (1168 Ma)	.998	Shoshonite	Syn-collisional	69.79	n.d.
LAM2	Basaltic Dike	Sierra del Puerte Canyon	n.d	1124.1 ± 14.1 Ma (0.82, 13)	Xenocrystic (1164 and 1260 Ma)	.818	Shoshonite	Within Plate	48.58	+6.7 ± 2.6 (MSWD = 9.4, 7)
LAM3	Basaltic Dike	Sierra del Puerte Canyon	n.d.	1123 ± 17.1 Ma (1.2, 7)	Antecrystic (1137 Ma)	.817	Shoshonite	Within Plate	48.7	+5.2 ± 3.3 (MSWD = 4.9, 4)

10. Discussion

10.1 Origin of Hf Compositions

A weighted εHf (t) value of +6.82 for S1 of the RBGS parallels the only other reported value of +6.6 (Howard, 2015), and the values for S2 , +5.26, +6.72, and +7.16, also coincide to a described value of +5.6 (Howard, 2015). Howard (2015) reported the only weighted εHf (t) value for S4 as +5.3, and we report the only values for the mafic dikes as +5.2 and +6.7 (as shown in Figure 17 and Table 2). These isotopic values show that both the granitic RBGS and basaltic magmas derived from a predominately mantle-derived source; with minor crustal incorporation. These values are very high relative to other sources within the SW United States and northern Mexico. The RBGS is peralkaline, fluorine-enriched, anhydrous, anorogenic, A-type, continental rift-related granites that formed from fractionation of mantle-derived magmas. Howard (2015) interprets the RBGS are mostly juvenile crustal material from the recycling of older crust based on the evolution and εHf (0) values. Unfortunately, to understand the composition of the magma at the time of crystallization the initial isotopic composition is needed. The εHf (t) values of the

RBGS are more radiogenic and therefore had only a small amount of crustal recycling. In our data, we do not see zircon inheritance from 1.3 to 1.4 Ga or older crust. The oldest xenocrystic inheritance was 1260 Ma. Also, the Hf isotopic values from this study do not support Shannon et al. (1997) and Howard (2015) that RBGS from the Franklin Mountains are juvenile crustal material. Instead, the Hf isotopic data support conclusions more closely related to Normal et al. (1987) and Ruiz (1989) that the mafic dikes and RBGS are mantle-derived.

Collectively, the weighted εHf (t) values for the Franklin Mountains range from +5.2 to +7.2. The only magmatic bodies that correspond to this radiogenic range are from the Llano Uplift, including granitic bodies from the +6.3 Grape Creek and the +6.5 Lone Grove plutons (Howard, 2015). Smith et al. (1999b) note the RBGS was emplaced into a shelf sequence north of the Grenville deformation front, and cite (Reed & Helper, 1994) that the granitic magmas of the Llano Uplift were emplaced into a deformed and metamorphosed crust. Our interpretation of the Hf isotopic values do not support the interpretation from Barker and Reed (2010) that the granites from the Llano Uplift are large-volume vertical magmatic migration in continental crust, the explanation from Howard (2015) of a component of older recycled crust, or the interpretation from Smith et al. (1997) that the ERB represents anatectic melts derived from crustal sources. The granitic bodies from Grape Creek and Lone Grove indicate sources that are mostly mantle-derived. A magmatic body with a εHf (t) value close to the Franklin Mountains is a quartz syenite from Pikes Peak at +4.8 (Guitreau et al., 2016). With other εHf (t) values from Pikes Peak including +0.4 and -0.8 (Guitreau et al., 2016), our interpretation agrees with Guitreau et al. (2016) that the PPB were shallow mantle-derived melts with direct crustal involvement, the more evolved representing the latter. Our interpretation also compares well with Smith et al. (1999b), that magma mixing played a role in the compositional diversity. εHf (T) values for Santa Margarita range from

-2.5 to +1.4, samples from Murietta granites range from -1.6 to +3.0 and -2.5 to +1.1 and the anorthosite from Sierritas Blancas range from -1.4 to +1.6 (Hantsche, 2015). Our interpretations of the more evolved εHf (T) values from northern Mexico that range from -11.6 to -6.6 agree with Hantsche (2015) that melts include a significant component of Paleoproterozoic Yavapai/Mazatzal Province crust. Epsilon Hf (t) values of xenocrystic zircons obtained in this study range from +10.6 to +12.9. Initial epsilon Hf values are higher than mean weighted averages from the same samples, indicating the older the inheritance, the more the source was mantle-derived. Further isotopic analysis is needed to refine derived sources of these three intervals, and to conclude if S5 has a similar source relative to the other stages. The pattern shows higher initial Hf values for the oldest temporal category; this provides further justification for the temporal categories due to their sources. The oldest temporal category, from the RBGS, is derived from a distinctly mantle-derived; whereas, the youngest temporal category shows little to no input from the mantle and depicts sources derived from crustal sources. The oldest temporal category likely represents a Proterozoic extensional boundary.

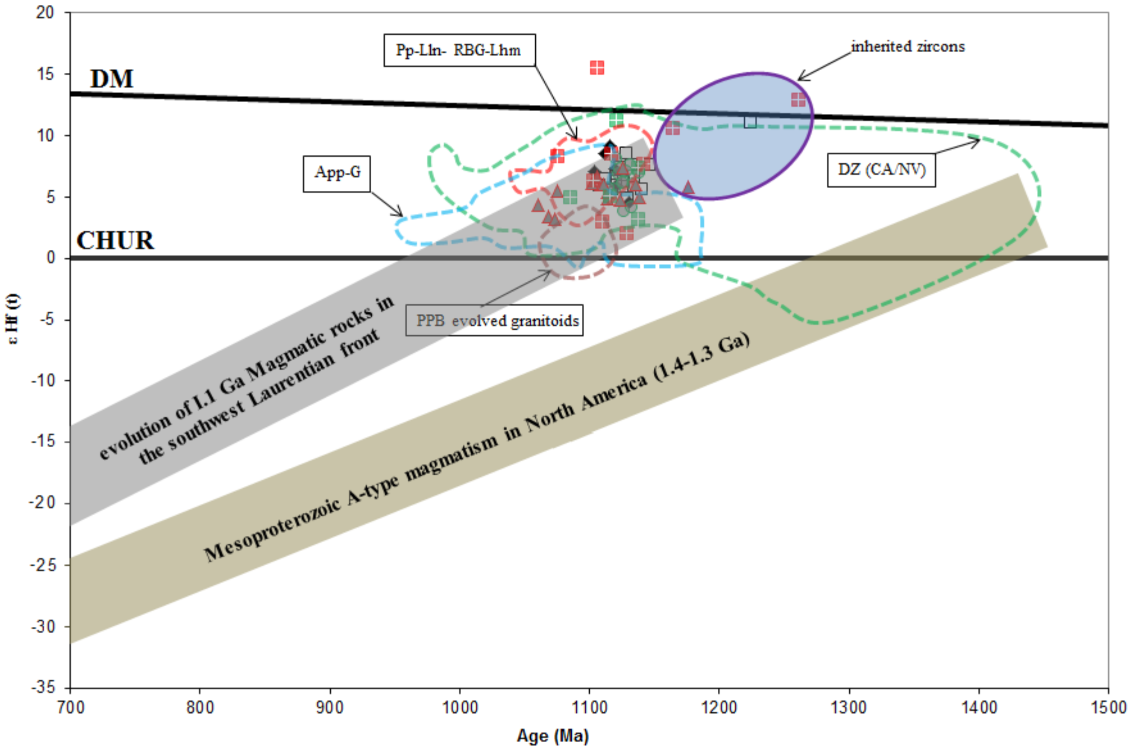


Figure 18. Hf evolution plot of Grenville magmatic bodies of the SW United States and Northern Mexico.

10.2 Timing of Southwestern Laurentian Magmatism

The Red Bluff Granitic Suite from the Franklin Mountains plots beneath depleted mantle on the Hf evolution plot. If the RBGS derived from older 1.4-1.3 Ga crust, then the evolution plot would follow the gray evolution path shown in Figure 18. An evolution plot from an older crustal source would plot as εHf (t) between -17 and -10. Pikes Peak, Llano Uplift, RBGS, and the Little Hatchet Mountains all plot beneath the depleted mantle in the area enclosed by red hash marks. This means the main volume granites at these locations have a small component of crustal inheritance. The Midcontinental Rift, Pikes Peak, Llano Uplift, Caborca, and the Franklin Mountains have magmatic representatives from two or three similar age groups; collectively these provided the initial evidence for various magmatic pulses. Appendix A.1 shows εHf (t) values relative to age, and Figure 19 shows the trend of the mean weighted εHf (t) relative to age of

magmatic bodies in the southwest U.S. and northern Mexico. The trend indicates that Hf isotopic values are less evolved closer to the end of the 1125-1100 Ma temporal category and more evolved relative to the 1097-1082 Ma interval. More samples from the 1081-1068 Ma are needed to see if a general εHf (t) trend can be more reliably justifiable. Southwest Laurentian magmatic bodies from 1125-1100 Ma are more a mantle-derived source than magmatic bodies from 1097-1082 Ma, even at the same locations. The 1125-1100 Ma temporal category represents extension before the onset of the Shawingian Orogeny, the 1097-1082 Ma category represents the end of compression and the beginning of extension during the Grenvillian Ottawan Orogeny, and the 1081-1068 Ma temporal category persisted completely within the Ottawan Orogeny.

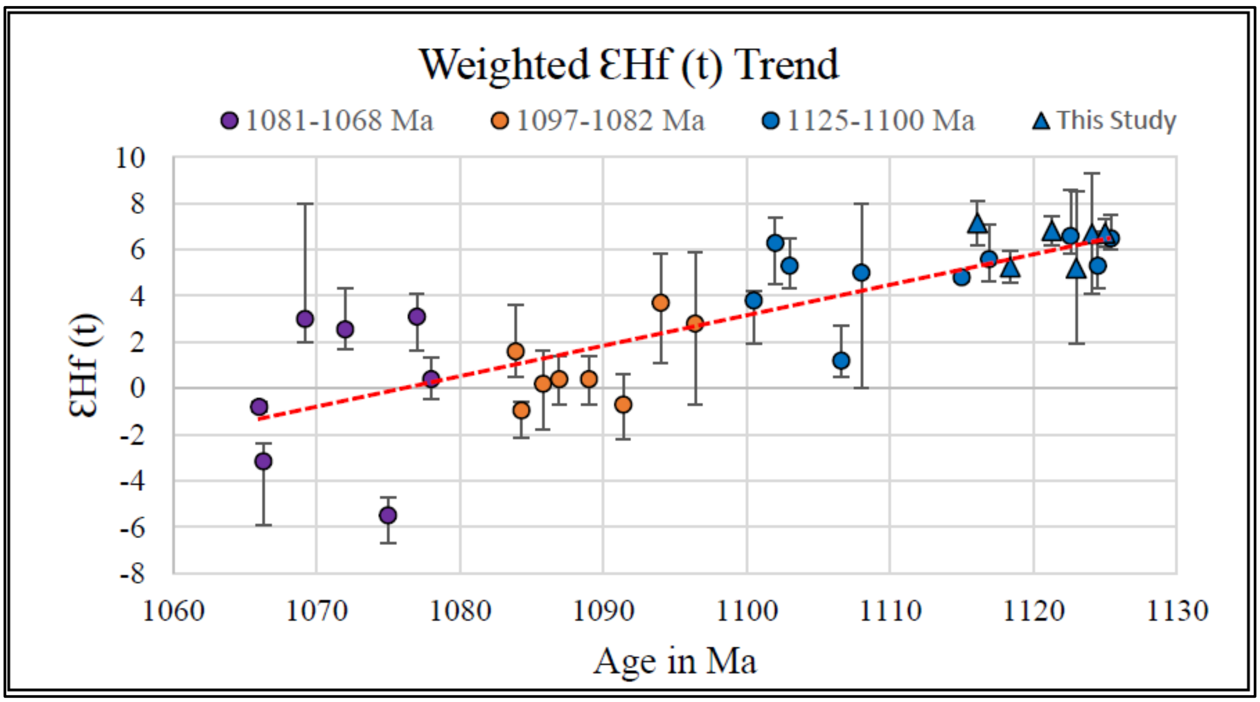


Figure 19. Weighted ƐHf (t) values for the magmatic bodies of southwest U.S. and northern Mexico. Isotopic values of the temporal categories distinguish variable sources. Modified from Guitreau et al. (2016), Hantsche (2015), and Howard (2013). The red dotted line is a linear regression for the Hf values.

Paleomagnetic data for the Keweenawan track from the Oronto Group poles were interpreted by Fairchild et al. (2017) from 1083 to 1070 Ma, which is within error of the youngest

magmatic age group. Fairchild et al. (2017) provide evidence that the Midcontinent Rift traveled more than 45˚ of latitude during magmatic events and 20˚ had occurred from 1095-1083 Ma. Volcanics and sediments from the Midcontinent Rift have representative units from magmatic age group (Fairchild et al., 2017 and references therein). Fairchild et al. (2017) suggested the age of intrusion below the unconformity represent a various structural developments associated with the extensional age of 1091.61 ± 0.14 Ma and new reported U-Pb ages represent Midcontinental Rift magmatic events in the Lake Superior region until 1084. New εHf (t) values of +5.2 to +10 (Solari et al., 2017) of Pinal metavolcanics near Cananea, Mexico and similar isotopic values from drill cores of the Sauk Sequence of Colorado (Hantsche, 2015) sandstones are older in age, yet are very similar in εHf (t) range to the RBGS of the Franklin Mountains and the magmatism of Llano Uplift. These igneous bodies that sourced the Sauk Sequence represent a juvenile source which is less evolved than samples such as the Wood Canyon Formation or the Little Hatchet Mountains. Hf isotopes from Guitreau et al. (2016) and Howard (2015) show Pikes Peak Batholith as more evolved than the Franklin Mountains and Aibo Granite being the most evolved.

10.3 Petrology of Red Bluff Granitic Suite

The Rb in S5 is ~3 to 5 times the values from all other stages. Ray (1982) reported that S5 is not genetically related to the other stages of the RBGS. Due to the high concentration of Ga, stage 5 does not plot with the other granitic bodies (see Figure 11b). Bowen (1919) mentions how rocks void of mafic minerals (such as S4) are derived by the processes of differentiation of fractional crystallization. A plot comparing Rb/Sr vs. Eu/Eu* (not shown) classifies the granitic dike and all stages of the RBGS as type-A granites, and none of the samples plot as arc magmatism. Shannon et al. (1997) stated S2 is younger than S4, but Ray (1999) indicated S2 intrudes S4, meaning the field relations provided contradict each other. Stage-3 and diabase dikes have not

yielded ages to date, and S5 was radiometrically measured in the 1960s. Ray (1982) suggests S5 is from a different magmatic source than the other stages of the RBGS based on texture, mineralogical dissimilarities, geochemical analyses, and petrographic analyses. Shannon et al. (1997) provided major element mass balance calculations to prove fractional crystallization from S3 to S2 to S4 was possible, a trend that Smith et al. (1997) also demonstrated with trace element models. Stage-5 is the only stage without overlapping fields and plots into granodiorite.

10.4 Tectonic Implications

The intrusion of Red Bluff granite is interpreted to be associated with the Mid-continent rift system in the cratonic interior of USA and is related to the enormous magmatism and emplacement of the Pikes Peak batholith (Barker et al., 1976) and coeval basaltic magmatism. There is no indication of subduction-related origin. Therefore, the observed geochemical characteristics are best explained by extension related phenomenon such as continental rift-related magmatism (Shannon et al., 1997). A2-types form either by differentiation of a continental tholeiite, with variable degrees of crustal interaction, or by direct melting of a crustal source that had gone through a previous melting episode (Eby, 1992). Figure 12c shows that the granitic dikes and all stages of the RBGS except S5 plot as fractionated granites. Cesium enrichment in basalts (as shown in Figures 13a-c) is due to late-stage hydrothermal alteration as evidenced by the partial replacement of plagioclase by epidote, and the Eu anomaly is typical of a feldspar fractionation trend. Strong negative Sr, Ba, and Eu anomalies and incompatible element enrichments along with high Ga/Al ratios are characteristics of A-type granites and indicate strong plagioclase fractionation of basaltic magma. According to Winter (2001), variations in HFS elements are controlled by fractionation processes during magma evolution, and the RBGS display evident such as Nb. PPB and the RBGS both display abundances of elements when normalized to OIB, but

both have Ta and Nb anomalies, which are not characterized with OIB. According to Winter (2001), high Ba and Rb suggest metasomatism or crustal contamination; there is a visible Ba trough within the RBGS. The trace element pattern of granites and associated ferrobasaltic rocks are subparallel with ocean island basalts and are consistent to be produced by fractional crystallization of a ferro-basaltic type sources, such as juvenile mantle instead by crustal melting. Geochemical analyses further provide evidence the RBGS are A2, within plate and formed from fractional crystallization. Rifting motion could have created the decompression to generate granitic magmas that could not be described by the Texas Lineament or the Walker-Lane Tectonic Belt described by Baars, (1995), Karlstrom et al. (1999), or Timmons et al. (2001). A Proterozoic transform fault correlates spatially and temporally with the magmatic bodies across SW U.S. and could explain the change in the direction of tectonic transport described by Davis and Mosher (2015). A Proterozoic transform fault proposed by Shannon et al. (1997) could help explain rifting features such as the mafic magmatic bodies described by Bright et al. (2014), the anorogenic granite suites of southwestern U.S. (Anderson & Bender, 1989), A-type granites of the Franklin Mountains (Shannon et al., 1997), arkose sandstones, paleocurrent indicators, soft sediment deformation, and valley fill of the Lanoria (Seeley, 1999), and soft sediment deformation ash beds, and localized brecciation of the Castner Formations (Pittenger et al., 1994).

The RBGS from the FM has the equivalent age and could also be associated with the same magmatic source as the Coats Land block based on U-Pb isotopic evidence (Loewy et al., 2011). New data presented here shows magmatic bodies from the FM and the LU have distinctly similar εHf (t) values and isotopically-defined ages, which represents strong evidence for the derivation of the same source. Post-collisional, mantle-derived mafic magmatism can provide the heat necessary for crustal anataxis (Bright et al., 2014 and references therein), but the RBGS and Llano

Uplift were formed in a similar tectonomagmatic evolution based upon initial Hf isotopic compositions at the time of crystallization, specifically from predominately mantle-derived melts. Tectonic indicators from Davis and Mosher (2015) point out the need for any tectonic model of southern Laurentia to explain how the direction of tectonic transport changed from northwest to north-northeast and finally to the northeast (Fig 20). Radiometric and paleomagnetic data from Loewy et al. (2011) confirms a clock-wise rotation for the Coats Land block. Tectonic models provided by (Li et al., 2008; Dasgupta et al., 2013) show the Rio de Plata continent was involved in an ongoing convergence with (present day) southern Laurentia by 1100 Ma, which were confirmed by subduction of continental crust from 1150-1120 Ma based on medium-T eclogites, and deformation of west Texas near the Van Horn area (Davis & Mosher, 2015). The Steeruwitz Thrust Fault emplaced 1.35 Ga metamorphic rocks on top of 1.25 Ga sedimentary and volcanic rocks and is the basis for the age displayed in figure 20a. The tectonic model of Mosher et al. (2008) show southward subduction of a margin of Laurentia culminated (1150-1120 Ma) with the collision of an arc, followed by continent-continent collision, crustal thickening, and uplift. The continental margin of west Texas close to Van Horn is interpreted to be a thrust belt that marks the northernmost margin of Grenville age deformation along the southern boundary of Laurentia (Mosher, 1998). Bickford et al. (2000) described that outcrops near Van Horn are essential to providing a clear transect across the Grenville tectonic front; whereas, Li et al. (2007) found no relation between the ages of igneous rock and the distance to the Llano front.

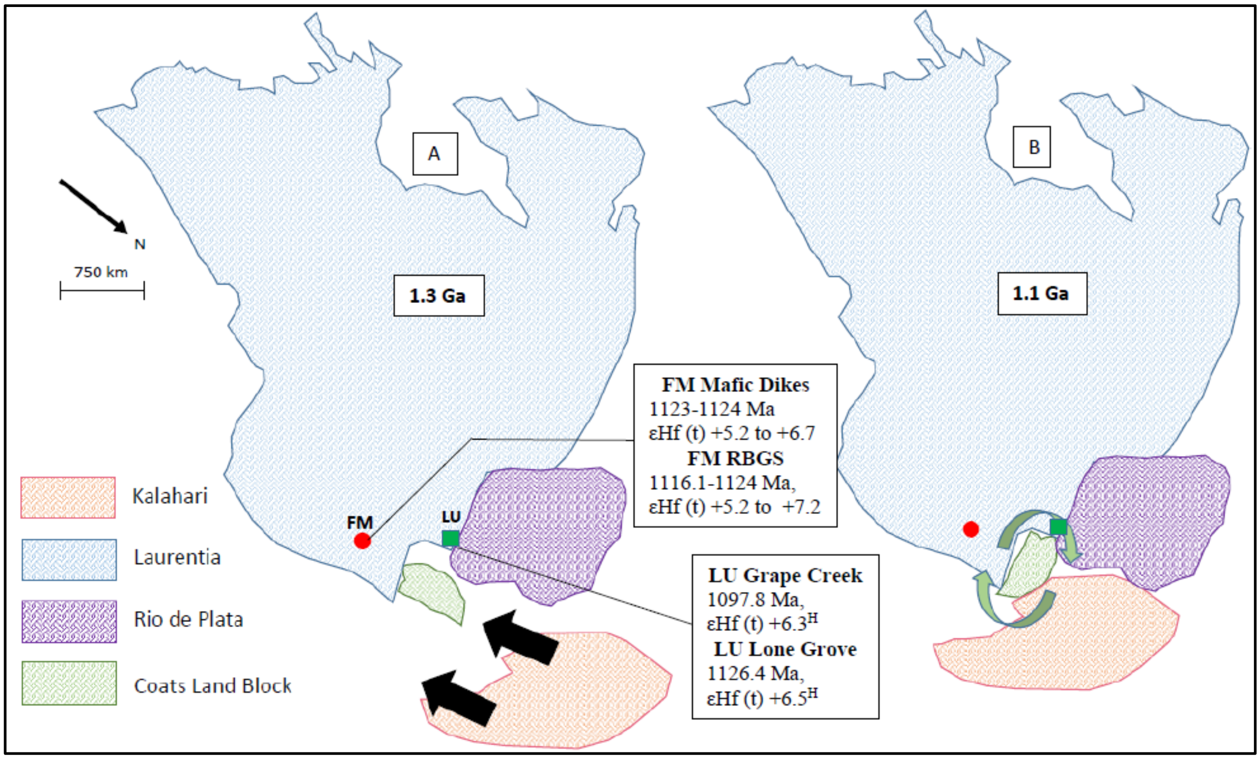


Figure 20. Tectonic model showing A) Coats Land Block prior to the arrival of Kalahari and B) Rotation of the Coats Land Block and resultant extension, modified after (G)-Guitreau et al. (2016), (H)-Howard (2013), Lowey et al. (2011), and Meredith et al. (2017).

By 1050 Ma the Kalahari block was in active continental collision with (present day) southern Laurentia (Li et al., 2008). The Maud belt developed between Coats Land and Kalahari (Lowey et al., 2011) and Rio de la Plata has been placed between southeast Laurentia and Kalahari in numerous tectonic models (e.g.Hoffman, 1991); Jacobs et al., 2008; Li et al., 2008; Meredith et al., 2017). These tectonic models indicate that Rio de Plata and the Coats Land block were an active collisional boundary prior to the introduction of the larger Kalahari block. The Kalahari block is likely responsible for the clockwise rotation of the smaller Coats Land block as shown in Figures 20 a-b. It is worth mentioning the FM are 750 km from both PPB and LU. The edges of the Coats Land block would have needed to separate from the rest of the continent and would be responsible for extension in southwestern Laurentia. The resulting rifts at FM and LU would then have facilitated decompression and partial melting of the sub-continental lithospheric mantle

(SCLM). Intracratonic sedimentation record extension prior and during the Grenville Orogeny (Mulder et al., 2017). Further isotopic analysis is needed to determine if units near Van Horn are related to FM, Coats Land, and the LU. The three continent-continent collisions of Rio de Plata, Coats Land block, and Kalahari could also be responsible for the three temporal categories presented here. Davis and Mosher (2015) point out the need for any tectonic model of southern Laurentia to first point out the difference in time between Llano Uplift of central Texas and the Van Horn area of west Texas (~60 Ma) and secondly, to explain how the direction of tectonic transport changed from northwest to north-northeast and finally to the northeast. The tectonic model described above could justify both of these situations.

During or at some time later Grenvillian convergence there might have been extension, and for that there are three possibilities 1) detachment of descending slab, 2) slab break off, and 3) slab roll back, which would coincide with the rotational model previously described. Each of these could facilitate asthenospheric upwelling which could possibly melt 1) SCLM generating alkali basalt which differentiated to A-type magmatic bodies or 2) partial melting of basaltic underplate (amphibolite). Whitmeyer and Karlstrom (2007) suggested basaltic underplating as a likely cause for bimodal magmatism and A-type plutons. Both of these sources can achieve the Hf isotopes and whole rock geochemistry we have. Partial melting of basaltic underplate could come from an island arc (alkali-rich) basalt and is likely reason for an alkaline basalt. With similar and relatively older ages, there is some inheritance of slightly older 30-50 Ma. So in a nutshell, either extreme differentiation of an alkaline mafic magma generated by partial melting of SCLM or partial melting of a new, recently underplated alkaline basalt.

11. Conclusions

Temporal, tectonic and isotopic Hf suggest variable temporal and source categories during the Grenville Orogeny. There are magmatic bodies within southwest U.S. and northern Mexico that represent three temporal categories of 1125-1100 Ma, 1097-1082 Ma, and 1081-1068 Ma. Locations such as the Midcontinental Rift, Pikes Peak, Llano Uplift and the Franklin Mountains have representatives of two or three temporal categories. Paleomagnetic track data of the Midcontinental Rift fit within two temporal categories, and Hafnium isotopic data shows a distinct trend within the oldest temporal categories. Our new age data within the error is consistent with the previously reported age of 1120 ± 35 Ma and of 1110 ± 19 Ma for the emplacement of Red Bluff granite (Shannon et al., 1997; Li et al., 2007). 1124 ± 12 Ma is the first reported age of the basaltic dikes that intruded the Lanoria Formation, and average εHf (t) values of +6.4 and +8.3 are the first reported Hf values. This is also the first report of the granitic dikes within the Franklin Mountains that are unrelated to the Red Bluff Granitic Sequence. Mineralogy, elemental trends and concentrations, geochemical analyses and initial Hf isotopic compositions all indicate both the RBGS and basaltic magmas derived from predominately mantle source; with little incorporation of crustal sources, and rotation of the Coats Land Block could explain the extension and decompression melting of the SCLM.

Chapter 2: Virtual Tour through Multidimensional Orders of Scale

Abstract

This paper presents information and an example of how Prezi™ software can provide an improved method for displaying spatial information when a background map is used as the central object in the presentation. As an example, the software is used here as an educational tool to create digital geologic field representations of a region in El Paso, Texas. A graduate class from The University of Texas at El Paso used Prezi™ to present map information in the Franklin Mountains because it gave them the flexibility to represent various scales of information accurately in a traditionally unstructured format. A geo-referenced aerial view provided the background and detailed geologic information associated with individual areas was layered onto this background at the appropriate locations. This allows individuals that are viewing this data to select a location of interest on the background view and then to get detailed information on that location by looking at different images, videos or maps from that area. Media is sorted by magnitudes of scale and the detail of information that is appropriate for an observation.

1. Introduction

There are many obstacles to taking students to the field. Field observations are difficult to duplicate in a classroom or lecture setting because these settings rely on 2-dimensional representations of 3- and 4-dimensional objects. We propose a method here to create a realistic field experience for a classroom or to accompany a field trip using Prezi™, a presentation software package that utilizes a background image upon which multidimensional data is layered. This enables a user to navigate from place to place and extract more detailed information. When the background image or canvas has a rational scheme and utilizes the background efficiently, we refer

to this as a structurally significant virtual tour (SSVT). Our primary example of a successful SSVT is to build a digital library of images and information on a satellite or map image of a region because this allows the representation of various scales of data to be linked to the physical position of the observations. Arrowsmith et al. (2005), De Paor et al. (2016), Jones et al. (2009), Martínez-Graña (2013), Stott et al. (2014) and Thurmond et al. (2005) are some that have approached multi-scaled digital representations.

The ability to make variable observations can enhance understanding of an area. Observations are dependent on orientation and how close or distant the observer is. Examples of different observable scales include examining a mountain from a distance, such as aerial or satellite view, holding a rock sample, observing outcrops, viewing crystal grains under a microscope or from instrumentation that give the elemental makeup of a rock. To address this issue a graduate class of in-service teachers learning geology used Prezi™ as one mechanism to create a multimedia website. The goal was to teach what a geologist does in the field. This culminated in a free educational tool that digitally quantifies magnitudes of scale along a series of outcrops beside Transmountain Road, in the Franklin Mountains of El Paso, TX. Presentations of the finished product were given to inspiring science teachers, and positive responses were surveyed.

2. Background

A field trip only has one scale, whereas a digital outcrop can represent a location at many different levels of scale, so relationships that are difficult to interpret in the field can be observed (Hurst, 1998). The concept of multi-scale and multidimensional analysis is national science standard; meaning educators must teach students how to create a model proving comprehension of Earth's processes at various spatial and temporal scales: HS-ESS2-1 (NGSS, 2015). The Franklin Mountains or any location should be examined at multiple physical scales to ensure a

complete understanding of the area. A 1:1 scale of observation can be envisioned as walking the mountain, where observations are literal, and one inch is equal to one inch. Larger and smaller scales are represented on maps, which are an instrument that allows us to visualize and observe that which is too big or small for the human eye. Aerial observations made from platforms such as Earth-orbiting satellites and aircraft extend from scales of 1:1,000,000 down to 1:12,000. Petrographic microscopes can make observations at scales of 10:1 to 400:1, Electron Microprobe Micro Analyzers produce data at scales of 10,000:1 down to 100,000:1, and visualizations of crystal structures extend scales of observation up to one billion to one. This project culminated in a Prezi™ presentation that incorporates this vast array of magnitudes of observable scale into a single, easily navigable representation. Each digital outcrop represents various quantifiable magnitudes of scale.

3. Methods

A graduate geology class at The University of Texas at El Paso (UTEP) was tasked with creating the virtual tour. Separate classes of undergraduate students preparing to enter the teaching field were surveyed after the tour was created to provide insight and critical feedback. Making a virtual tour begins with geo-referenced programs such as NASA's World Wind ™, Google Earth™, and Flash Earth™ allow the user to zoom to various orders of scale to help constrain the parameters of scale to take a screenshot or satellite photograph of an area of interest. A smartphone equipped with Google Maps™ can be used to locate longitude and latitude. These positions can then be entered into these geo-referenced programs. This serves as an accurately geo-referenced map. With the canvas in place, media such as pictures, audio, maps, drawings, diagrams, Youtube™ and Explain Everything™ videos were inserted on top of the satellite view at precise locations. After media is added to the canvas the wheel on the mouse helps to zoom in-or-out of

variable levels within the presentation this enables media to be embedded and layered on top of other media. The zoom-bar on the right-hand side also helps complete this task. This means there is an entire library of site-specific media on top of a spatially-dynamic satellite image.

Figure 1 represents a conceptual model of the SSVT created for the Franklin Mountains. The background is an interactive canvas, and the line represents an ~11km road through the Franklin Mountains. Media is layered on top of each location to represent outcrop locations.

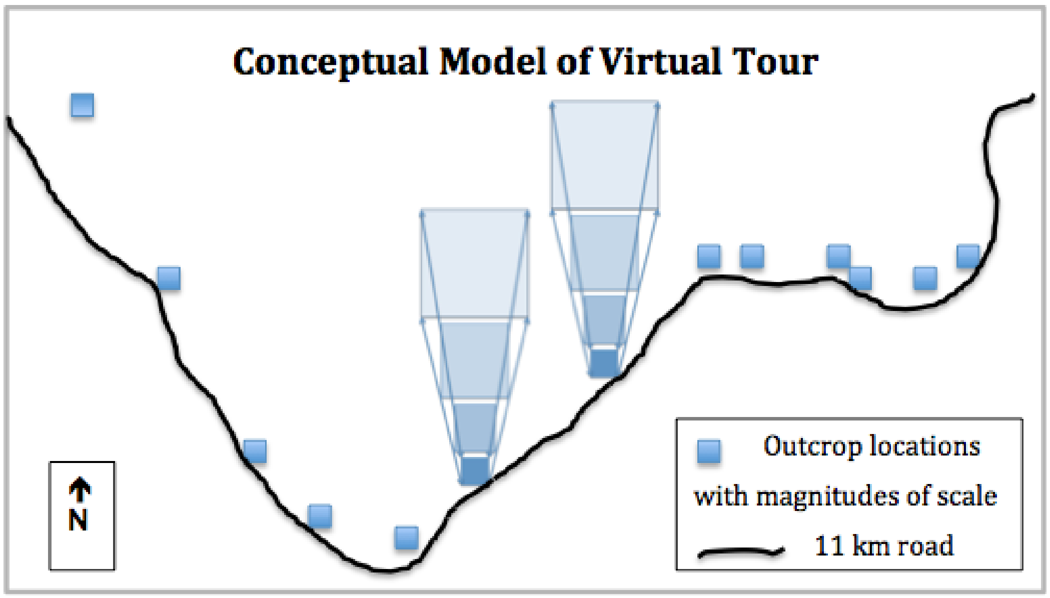


Figure 1. Shows the concept of a structurally significant virtual tour (SSVT) along Transmountain Road, Loop 375. The line represents the road, the boxes signify field locations, and the boxes on top of each other represent digitally layered magnitudes of scale at these locations. The background represents the satellite image.

Location navigation is available by clicking on the desired location, which instantly takes the user to that specific location on the map's canvas. Once at the outcrop, clicking the "Next" arrow on the bottom of the screen brings another view of the same outcrop, but this outcrop is interactive and ready to be explored. A student example is illustrated in Figure 2. After clicking "Next," audio can be heard via added path voice-overs, thus while the outcrop/road cut is investigated, audio from each student can be heard based on that individual outcrop. Web-based resources from that exact location such as a Gigapan™ provide interactive pictures from seamless

web integration that enable investigation of further magnitudes of scale. Gigapan™ uses high definition pictures created from a specialized mounted and motorized camera that takes hundreds of pictures and combines them into one image that can be virtually navigated on the web. Each click on a Gigapan™ photograph zooms in 10 times, and this makes orders of scale easily manipulated. Gigapan™ houses free pictures of outcrops, polished slabs of rock and locations from the Franklin Mountains and at other places around the world.

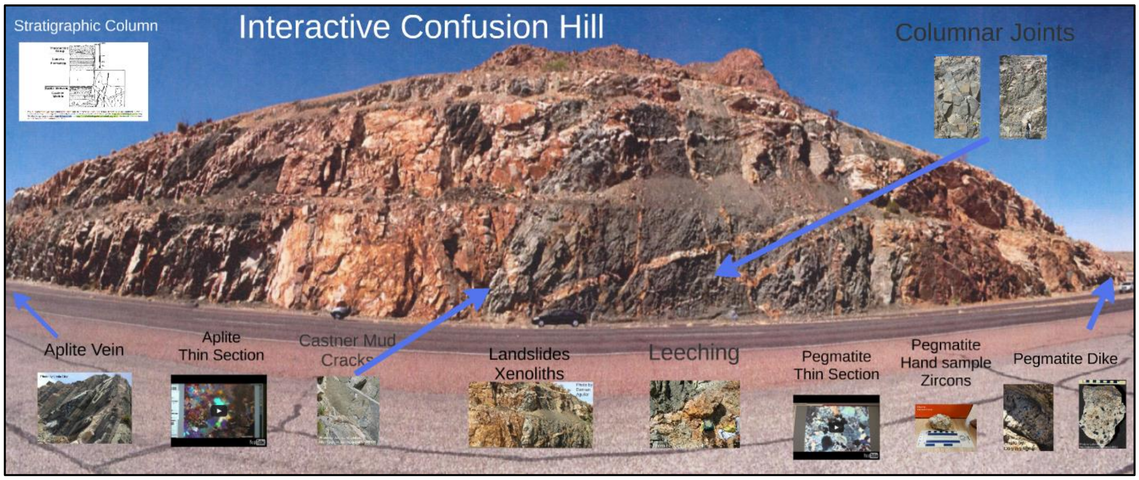


Figure 2. Shows one of the many interactive outcrops within the virtual tour.

Student drawings of vertical sections quantitatively describe outcrops. Figure 3B shows a student example of a vertical section; Figure 3A represents the outcrop this student depicted. This drawing is to vertical and horizontal scale and has designated areas of interest within the outcrop of different layers. Students were assigned to map areas distinguishing uniformitarianism and catastrophic occurrences accurately. While students were making these quantitative vertical sections, hand samples were obtained to create individual thin sections, polished slabs, and samples for the Electron Probe Micro Analyzer based on individually assigned locations.

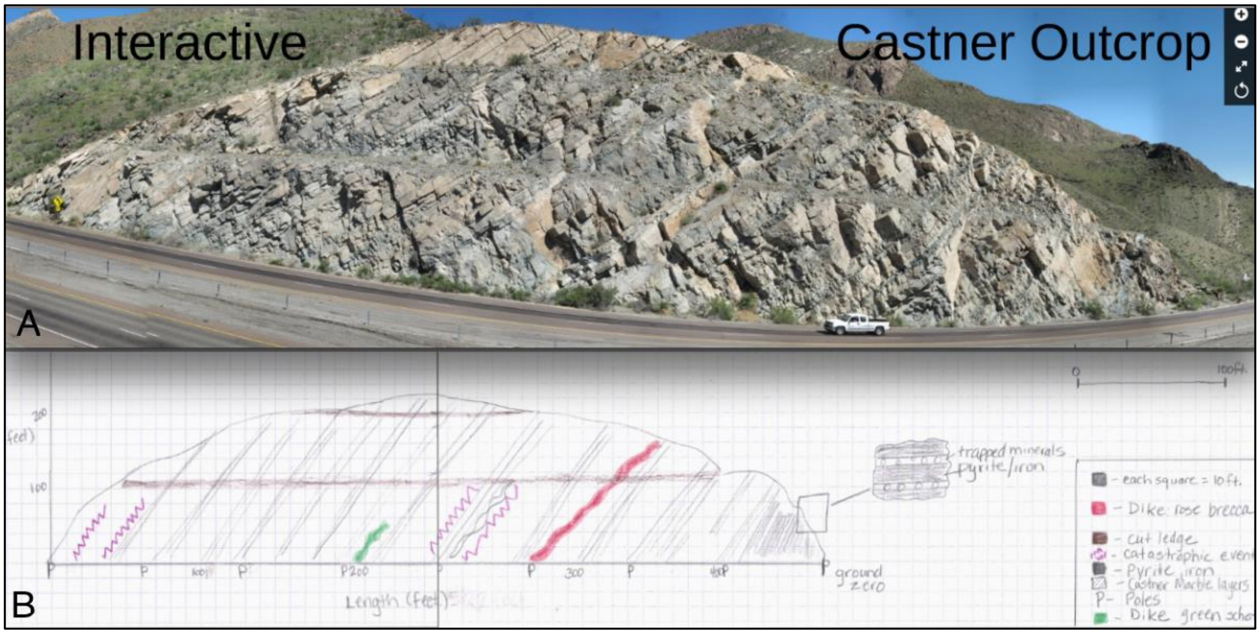


Figure 3 Shows an outcrop location of A) interactive Gigapan image and B) vertical section of the outcrop.

Graduate students were able to create visualizations of mineral structures by first downloading free .cif files from websites such as rruff.geo.arizona.edu, and then explore these files with a free program called Discovery Studio™. Before the creation of the virtual tour teachers were informed of other canvas-based programs that could potentially work similarly, such as SMART Board™. Ultimately teachers elected to use Prezi™ due to it being free. Figure 4 shows the levels of observable scale included in the virtual tour.

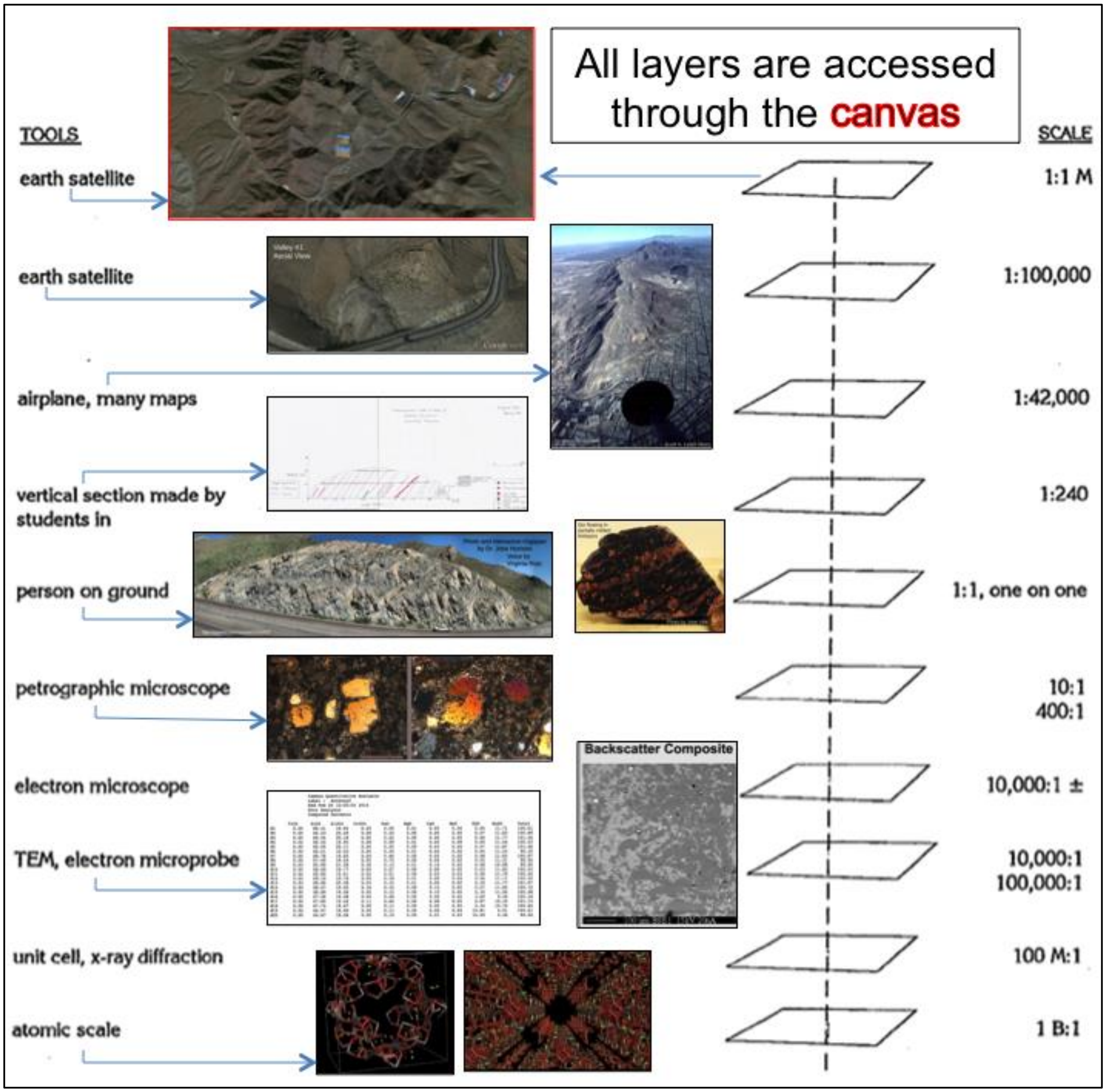


Figure 4. Displays the levels of observable scale that are demonstrated within the virtual tour of the Franklin Mountains.

4. Advantages of Digital Field Representations

Graduate students challenged with creating field representations with an apparently logical scheme to represent media. The method describes a coherent organizational scheme that not only the presenter is aware of, but more importantly that the audience can easily navigate, understand

and follow. In general, virtual tours use either use a linear relationship or no relationship to represent the world. Earth should not be represented in these traditional methods. Abrams et al. (2011) point out that with Prezi™, manipulation-based relationships between pieces and the entire concepts can be visually illustrated. Digital field representations can be aesthetically and kinesthetically appealing, easy to navigate, can enable users to work at their own pace and should be easy to access and navigate.

The overall creation of the VT appeals to all learning styles. Visually-spatially learning is represented via the group's depicted canvas and by individual hand-drawn representations of the vertical sections. Path voice-overs apply auditory learning. Tactile learning is incorporated with a hands-on approach to creating thin sections (or microscope slides) for petrographic microscopes and most importantly, and probably the most neglected learning style is naturalistic, that was incorporated by interpreting and describing geologic events such as microprobe analysis, relationships of rock units and Youtube™ video interpretations. If the SSVT is made available to students before-hand, they would have the opportunity to learn at their own pace and would be able to explore when, where, and what they want. This would create a flipped-based classroom, where learning happens before the scheduled class meeting, and face-to-face meetings are really for discussion and elaboration. Kurkoski (2013) suggests active learning, hybrid courses, and podcasting are ingredients of flipped classrooms and that these newer pedagogical practices now seek mastery of the material. Virtual tours represent active learning, informal science, and a means of connecting with others.

Virtual Tours would be extremely beneficial for those with disabilities, such as limiting movement or physical or temporary disabilities, such as a broken hand, leg or foot. There is always the chance of adverse weather, but in general, there are many reasons why an area could be

“inaccessible;” specific examples would be if a country were war-torn or disease stricken. The location along which the virtual tour has outcrops and road cuts is along a major U.S. highway, which creates safety concerns for high-speed traffic and falling rocks. Stott et al. (2014) report digital field representations allow integration of media such as images, data from a laboratory, observations, and connections, but most importantly fieldwork approaches and techniques are taught and learned.

Another pronounced advantage to Prezi™ is the ability to work seamlessly with other technologies. Prezi™ can work with SMART Board™ technologies and mobile technologies (such as a smartphone or tablet); this means that a user can interactively touch the desired location and instantly zoom into that portion of the SSVT (as opposed to a click of the mouse); then the presentation can progress forward or backward from that point on and at any time have the option of returning to the aerial picture-based canvas. With a SMART Board™, the user can write on or illustrate the canvas with the stylus at any time, highlighting on top of the presentation. Mobile technologies enable the user to pinch the screen and zoom in-and-out of all pictures and places within the display, which increases moving functionality within the presentation. Prezi™ software has the capability of allowing multiple users to work on one presentation simultaneously. Also, Prezi™ can be presented remotely through the use of a live link. A live link enables others to follow along (even without Prezi™ installed). Creating an account, uploading and retrieving presentations to the web and using desktop versions (when there is no Internet) are all free.

5. Problem

Although there are few exceptions to “boots on the ground” fieldwork, we create a digital representation that can allow for instantaneous access to various magnitudes of scale at multiple locations that are free and without having extensive background knowledge of the creation of

programming language (or website code). There are many good virtual field trips/virtual tours, but many do not allow for manipulation, exploration, or discontinuity from the linear format. There is no structural significance to the canvas of notable Prezi™ presentations; for example, the Prezi™ that won the Ideas Matter Contest of Prezi™ and TED competition did not have visual or spatial significance to the canvas; instead used the canvas as an artistic transition tool (Groenendall, 2013). Abrams et al. (2011) also point out many cons to using Prezi™, such as ineffectiveness, visual discomfort, difficulties with understanding and use of software, and the inability to print the presentation.

Official course surveys and discussions with graduate students describe the main struggles of the VT creation were (first) there was no Home button (at the time of creation) or way to return to an overview without designing the VT on a single image. The most prominent struggle was once the presentation file got large enough the Adobe/Flash-based Internet browser would take a while to load on computers without processing memory of <8GB. The problem was reduced with the new Java-based player for Prezi™. The new player also created a Home (overview) button, but the main drawback with the new player is the inability to overlay additional layers beyond adding more than one on top of the canvas. Although most students from the class created their own movies of 3D mineral structures, most students did not extend the order of scale to the atomic level for individually assigned locations. Finally, as a student-based product there needed to be a statement signifying that there is the potential for some errors. Currently, the default player set minimizes the quality of pictures. There is a statement under the player that mentions to "go back to the older viewer." If you click that icon, then the player will have higher image quality.

6. Results

This product will serve as an education needs for many audiences, such as local early colleges and high schools that teach dual-credit geology, secondary learning institutions and visitors of these institutions, or the public in general. This idea was presented locally for miniCAST, Science Teachers Association of Texas science dinner, science outreach for early college students, and for preservice and in-service teachers. The concept was also demonstrated nationally at American Geophysics Union Fall 2014 Meeting under the category: Games, Interactive Simulations (Alvarez et al., 2014), and Virtual Labs for Science Teaching and Learning, Insights Science Museum. There have been over 1,000 different viewers to the virtual tour, and data from the electron microprobe is now housed on the departmental geology website for the university.

Graduate geology students from UTEP involved in helping create the virtual tour were surveyed, and the results showed all students said they would consider structurally significant presentations in the future. Undergraduate students from two science methods courses at the same institution were surveyed in the spring of 2015 after a demonstration of the VT was displayed. The survey questions using a Likert scale modified from Stott et al. (2014) resulted in conclusions from these preservice teachers.

Surveys from 35 preservice science teachers from The University of Texas at El Paso showed:

- 32 Would recommend the virtual tour to others
- 34 Believe virtual tours can help prepare for fieldwork
- 31 Agree virtual hours helped to understand the processes that shaped the local topography
- 28 Agree virtual tours should be incorporated into other classes
- 30 Agree virtual tours increased their interest in the local area

7. Alternative Methods

What makes a good map is the ability to create functional layers within the map; examples would be Google Earth™ (ability to overlay roads, international boundaries, plate boundaries, etc.) or ToxMap™ with the ability to overlay amounts of chemicals released and environmental factors with human health. There are many good ideas out there about layering maps, such as Jacobson et al. (2009) discuss the concept of manipulating map layers using Adobe/Flash opacity sliders for comparisons and combinations of layers. The layered image file format .liff is a commonly used by GUI software such as Open Lab™ suite. GUI- stands for a graphic user interface, referring to software that does not require learning programming code.

Open Source Technologies discussed by Stott et al. (2014) report the World Wide Web Consortium, where free templates are available, Geoscience Markup Language, where a catalog is in place of geologic units, structures, and mapped features, and Exhibit software which has templates for web applications. Semantic web facilitates cooperation of people and Internet services if the information is well defined (Berners-Lee et al., 2001). Exhibit and other software, discussed by Stott et al. (2014) represent semantic web technologies.

8. Conclusions

The educator of today should have a classroom without boundaries, and the number of assets and resources available to students should be accessible anytime, anywhere. Influences of technology and web-based content open the world even further, expanding both teacher and student knowledge. The presentation on a picture method builds on an organizational scheme the audience can understand and follow that detaches from the traditional linear method of organization while creating a structural significance; this allows for dual function: one click to enter any geo-referenced location, where multiple magnitudes of scale allow for manipulation, and

one click to view the overview (aerial view) thus creating seamless transition between micro and macro scales. Incorporating a VT into in-class activities might grab more attention from the students and help them relate to topics. The ability is here to expose students to resources that may not be a possibility, such as field trips. This will allow for exposure to the geosciences to all communities. Plus, you could link to other organizations, such as science centers. The process of multiple levels of investigation at manipulative orders of scale and data created upon an accurately geo-referenced structurally significant canvas and then followed by synthesis, integration, and conclusions has few parallels in science or pedagogy. The virtual tour is available at http://prezi.com/ppifmprmx4jr/

Chapter 3: Two Methods to Describe the Vastness of Time

Abstract

Here we illustrate two methods to describe the vastness of time. Various field and technology-integrated approaches were used to construct videos illustrating the geology of specific locations for the first group of practicing teachers. The videos were organized into a geo-spatial and chronologically organized virtual tour which collectively shared the billion year geologic story of the El Paso/Juarez region and described systematic tectonic and paleogeographic changes to North America through this time. Non-related flipped-based learning videos were provided for a second group of grant funded teachers part of the Texas Regional Collaborative; these videos were used for field trips to El Paso's Great Unconformity. Instructional methods were designed to calculate the date local formations proportionally relate to a 12 month calendar with respect to all of Earth time. For example how approximately five hundred million years of rock record went missing. The aim of both the class and the grant were three-part: 1) introduce emergent technologies, 2) focus on pedagogical tools and cultural significance, such as problem-based learning, flipped-based learning, constructionism, connectivism, and sense of place, and 3) teach Earth science based content in order for teachers to describe how local landforms are made and change over time. The combination of these concepts and tools will give future teachers the ability to apply new and emerging technologies into their classrooms and the ability to learn and teach geologic concepts such as the vastness of time, in order to integrate these concepts into in their future classrooms.

1. Purpose and Learning Goals

Approaches to learning are changing as fast if not less rapidly than technologies are emerging. The demands for methods to teach in a constantly progressing digital era are

consistently increasing in need and cost. The challenge is to teach emergent ideas within an established theoretical framework. The TPACK framework, which integrates technology, pedagogy, and content knowledge was used for two groups of practicing teachers in order to learn and ultimately teach the concept of the vastness of time. The first group was a college level Computer Applications in Earth Science course taught in spring 2015. The goal of this course was create a virtual tour (VT) that avoids the pitfalls of presentation media which use background transitions, images and animations with no functional purpose, confusing the student and the presenter. Having a goal for the content of a presentation gives purpose to the design of said presentation. The virtual tour described here used emergent methods in TPACK categories in order for practicing teachers to use their own teaching styles to create a small piece of the overall story for the local geology. When the individual stories are combined collectively, the regional billion year paleohistory of the international border between the western most point of Texas and Mexico is told in a geospatially and chronologically organized VT. The aim was for teachers to take TPACK methods into each and every one of their future classrooms and to create an educational tool that can be used for geology students or teachers, students with disabilities, schools that may not have the financial means for class field trips, and students from out of town or the public in general to view a potentially inaccessible story.

There is a need for teacher empowerment in science education in Texas. According to Texas Assessment, 5th and 8th graders in 2015 and 8th grade students in 2016 from the largest local school district scored lower in every science reporting category than state and region averages. The averages of local students at this time were up to 20% lower than state and region averages (Texas Assessment). In the state of Texas, exam scores in April 2015 of 5th and 8th grade students showed that students scored lower in the Earth and Space Science reporting category than any

other category and in April 2016, 5th grade students scored lower in Earth and Space Science in 19 out of the 20 regions of Texas (Texas Assessment). Due to obvious deficiencies such as these, grants such as the Texas Regional Collaborative provide teacher trainings focused on Earth science.

The second group was a teachers' workshops and field trips, the Texas Regional Collaborative, which took place in the fall of 2015. The main goal was to teach the vast geologic span of time in the El Paso region using El Paso's Great Unconformity, a series of missing rock representing a large gap in Earth time. Trainings that incorporated field trips and workshops focused on proportionally relating Earth history to specific dates on a 12 month calendar year. Formations seen during field trips were assigned calendar dates in order to develop an understanding of local geology, their sequence, and major changes to North America over this time span. Our subject was the billion year history of the region's diverse landscape that is the product of many individual events, including volcanism, erosion presenting as missing time, dinosaur activity, tectonic deformation represented by past compression and an active divergent boundary. These collectively would establish place-based learning for teachers and generations of their students. Place-based education allows for the localization of standards and encourages educators to utilize local resources to relate students to relevant concepts using the location they live in and go to school in (DeFelice et al., 2014). Local teachers need to be aware that due to the region's diverse geology and quality of exposed rocks in this far west region of Texas, field courses from all over the nation, and world, come to the Franklin Mountains as a learning experience.

In order to establish this context and cultural significance, a flipped-based technique was applied, where local K-12 teachers were shown geologic-based concepts through the use of instructional videos, shown prior to field trips which were accompanied and lead by local

geologists. The Flipped Learning Model (FLM) is a method of blending learning both within and outside the classroom (Huereca, 2015); online videos, course materials or lectures are made available prior to class meetings. This enables deeper learning and higher-order thinking during class activities and discussions.

2. Literature Context

Education is the integration if content, pedagogy, and technology. These elements establish a theoretical framework known as TPACK that was first described by Niess (2005) and Mishra & Kohler (2006). Both groups required guidance and support in all three domains.

2.1 Technological Knowledge

There have been many advents in virtual tours, along with all the breakthroughs there are also downfalls and obstacles to some of the methods that have been used. Approaches to virtual tour representations have been created by Arrowsmith et al. (2005), Thurmond et al. (2005), Jones et al. (2009), Martínez-Graña et al. (2013), Minocha (2014) and Stott et al. (2014), De Paor et al. (2016), and Bursztyn et al. (2017). Arrowsmith (2005), Jones et al. (2009), and Thurmond and others (2005) describe methods using GIS and virtual reality modeling language (VRML). Arrowsmith (2005) created interactive questions, panoramic views and a heads-up-display to create a VT and Jones and others (2009) created a graphic user interphase, but neither provide a link to the tour or links from the published figures they used. Examples like those from Arrowsmith et al. (2005) and Thurmond et al. (2005) do not work in every geologic example around the world. Further, extensive knowledge in GIS, VRML and HTML are required to effectively create similar tours. Martínez-Graña et al. (2013) use QR codes implemented with mobile devices to construct augmented reality with Google Earth™. This method could be adapted, but ultimately would be best utilized while users are at specific locations and more importantly have access to specific

technologies such as smart phones. Transportation, funding, and accessibility are some of the constraints of travel to the most desirable locations for such all-encompassing destinations. Minocha (2014) combined concrete geologic concepts with aerial photography and LiDAR using Unity 3D. Unity 3D is a gaming software that creates 3D landscapes, but extensive funding was required and the resources created are not free to the public. Stott and others (2014) designed several virtual tours, but the link provided to access these virtual tours no longer works and an extensive background in website software Dreamweaver™ and in Javascript code written in Exhibit™ are required no devolve these VT. De Paor et al. (2016) also used Google Earth™ to create a virtual tour, and even though Google Earth™ is free to the public, the design of the VT is complex, grant funded, and the link provided in the manuscript takes users to a login-screen. Bursztyn et al. (2017) showed that students that completed simulated field trip experiences were significantly more interested in learning geosciences when compared to control students; clearly illustrating the utility of the VT. Thus we sought to find a method to create an accessible and informative VT. The techniques we describe below, to create a VT are free, accessible to anyone with internet access, a competent processor, and most importantly do not require extensive background knowledge in technology.

2.2 Pedagogical Knowledge

Teachers took charge of their own learning and research, then combined theory and practice based on their own knowledge, skills, and learning (using metacognition) to solve a problem; this is referred to as problem-based learning (Savery, 2015). Technology influences how society functions and comprehension has now evolved into a digital era in what Siemens (2005) termed connectivism. Another way of saying this is that today's learners are known as "Digital Natives" (Prensky 2001). The overall class project reflects not only problem-based learning, but

it also reflects project-based learning due to the required end product (Savery, 2015), which was a collection of online videos integrated into a virtual tour. Both groups of in-service teachers learned new TPACK methods of content and pedagogy from the instructors, and technology from teaching assistants and focused on a FLM. A study by Love et al. (2014) showed students in a FLM classroom had a significant increase in exam scores for the duration of a linear algebra course when compared to students in a traditional lecture setting. Materials were provided following a FLM. This enabled students to have a background of knowledge and a place-based geological context prior to field trips. Collectively, these concepts relate to the teacher's sense of place. A sense of place was an introduced theme that was elaborated heavily throughout the workshop and class. The tactic was proposed for teachers and students to help identify aspects of nature that were encountered in the field. Semken & Freeman (2008) have shown significant gains in learning using place attachment and place meaning. One of the most important techniques the class used was called constructionism. Constructionism is focused on learning while "making things" with an amount of acquired ownership (Ackermann, 2001). Constructivism is also a form of student-centric learning, but is based on an evolution of thinking (Ackerman, 2001). Constructionism always requires a tactile component of building or creating and ownership; neither of which are required in constructivism.

There are many reasons to make teachers aware of new and prevalent teaching philosophies. Providing teachers with new tools, better prepares them and ultimately helps alleviate the revolving door of teachers. A longitudinal study showed that after five years, 29 percent of teachers moved to another school and 17 percent stopped teaching (Aragon, 2016). The U.S. Department of Education (2016) reported that every year from the 2009-2010 school year to the 2013-2014 school year, the number of K-12 student enrollment has increased and the number

of individuals enrolled in teacher preparation programs has decreased. In this time, enrollment in teacher preparation programs went from 725,529 down to 464,250. Sutcher et al. (2016) report the U.S. has a teacher shortage and if trends continue the shortage will become more problematic.

2.3 Content Knowledge

The history of Earth is on the order of billions of years. This concept can be difficult to understand or visualize because not many deal with such great numbers. This has led educators in the past to compare all time on Earth, which is approximately 4.56 billion years old (Allegre et al. 1995) to concrete concepts such as time within one class period, days, or a calendar year (Eicher, 1968; Sagan, 1977; Hume, 1978; Ritger and Cummins, 1991; Metzger, 1992; Everitt et al., 1996). These are concrete concepts that are proportionally compared because most understand the concept of one year having 365 days, 12 months, etc. These works describe the oldest rocks on Earth but are not place based, describing what local students are looking at on a local mountain, valley, outcrop or landform. Specifically, these methods describe the vastness of time, but are not applied to the intricacies of local El Paso/Juarez geologic history, including the formation of rocks, missing time, and or the formation of mountains, hills, or valleys. In this sense none of the methods previously described are applicable place-based learning.

3. Reachable Demographic

El Paso, Texas and Juarez, Chihuahua, Mexico collectively make the largest international border population in the world (City of El Paso). According to the U.S. Census, almost 81% of the population of over 680,000 residents in El Paso is Hispanic and over 70% of people five years and older speak a language other than English at home. The percentage of people without health insurance under age 65 is more than 252% higher than the national average and more than 1 out of 5 are living in poverty, also a number much higher than the national average (U.S. Census).

The per capita income, mean household income, and both the percentage of persons 25+ years of age to graduate high school or receive a Bachelor's degree are all considerably lower than U.S. averages (U.S. Census). The language and educational deficiencies in this region are clear.

Two groups were shown methods to learn the vastness of time. The graduate Computer Applications in Earth Science course was composed predominately of in-service middle school and high school science teachers. There were two international students that resided in Mexico but make the daily trip to attend university classes in the United States. All the students in the class had attained a Bachelor's degree and were working toward a Master's degree in Geology. The teachers were working to attain 18 graduate hours in geology. With 18 graduate hours teachers would have the ability to teach college or dual credit courses in that specific content area. Most of the class had little to no experience or preexisting knowledge of the Earth sciences.

The Texas Regional Collaborative Grant was made available to anyone who wanted to join and was willing to commit to 100 hours of professional development. Practicing teachers were recruited via emails and flyers sent to school and district science personnel. All participants were from Title I schools, which are schools that have high percentages of students from low-income families. Approximately 20 were 3^{rd} through 5^{th} grade teachers and approximately 10 were middle school science teachers. The trainings centered on Earth and space science needs based on school, regional and state data. Grant participants had some knowledge of Earth science related topics, but due to the scarcity of these topics covered in elementary schools and the majority of these teachers being elementary teachers, very few had the ability to incorporate local geological concepts into their classrooms. The race and Hispanic origin of both of these unrelated groups matched the local population.

4. Materials

4.1 Virtual Tour: Graduate Class

Prezi™ software is an alternative presentation medium that uses motion, zoom, and spatial relationships. All that is required is an email for the free basic version. Presentations that are created are stored online for free and can be saved and displayed offline as well. Any program has a learning curve, but this software is easy and accessible. Once an item is created in Prezi™ it can be accessed online via a created web link. Edits made to the VT are instantaneously saved and do not alter the link, so no matter how many changes are made the link remains the same. The VT uses a web-based medium housed on an accurately geo-referenced background in order to construct a visually, spatially, and chronologically organized design. The background plays a vital organizational aspect, described by Alvarez and others (2014), which allows navigation to-and-from locations and the ability to zoom in-and-out to information and data at various locations on a master map with relative ease.

Prezi™ software has the ability for the users to seamlessly navigate from one location/concept to another. This is done when looking at the small scale master map of the presentation. The user can click on any presentation point on the master map and the program will take the user to that location to view the information included at that presentation point. Varied data can be inserted into a presentation point as with PowerPoint™, however one is not relegated to a single slide. Part of the power of Prezi™ vs. PowerPoint™ is that one can see the overall master map/order of the presentation and still decide to skip to points of interest without following a pre-determined presentation order. Presentation points in Prezi™ can be scaled and overlapped relative to the master map of the presentation. So, while the whole map may be large visually, as one selects or zooms into a presentation point, more and more data can be observed and/or input

by the presenter (Figures 1a, b, c, and d). In essence, a point with a title on the small scale master map can be selected or zoomed in on to reveal numerous examples of text, images, and video links (Figures 1a, b, c, and d). The user can easily return to the master map using two methods, one can click on the home icon or on any location on the master map.

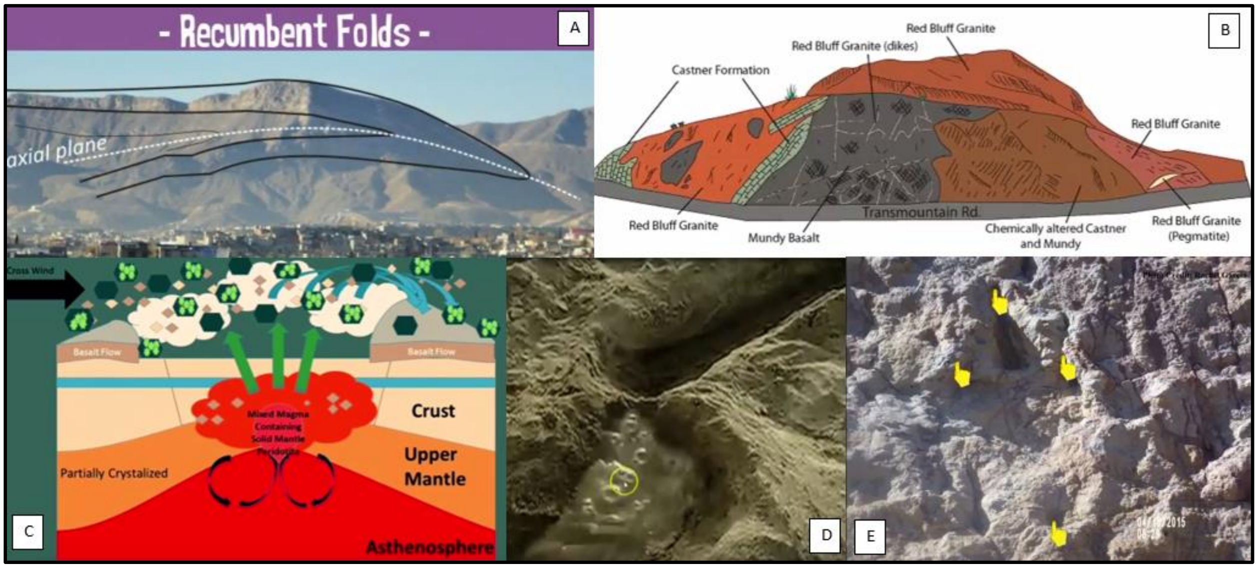


Figure 1. Shows examples of student work incorporated into the VT, such as A) recumbent folds photo credit Bentley (2012), B) landslide deposits photo credit Villalobos (2013), C) digital depiction of maar volcano and how mantle is exposed on the surface of the Earth, D) student-produced model showing lake formation and E) an animated video of the dinosaur tracks in the Mojado Formation. Yellow hands point to toe impressions at one of the tracksites photo credit Rachel Garcia.

Examples of the technologies used by presenters that were taught through the duration of the class are shown in Table 3. Online hard drives have the ability to store and share files. Screen-casting is a term where all or a portion of the computer screen is selected and whatever video that is displayed on the screen is recorded; this generally is used in conjunction with audio recordings. Interactive whiteboard apps allow the users to create videos using pictures and text; illustrations are frequently used during audio/video recordings. These apps are an easy method to create online videos for FLM. The majority of the videos were created using Screencast-o-Matic™, PowToon™, Educreations™ and Explain Everything™. All of the visualization software listed

in Table 3 are free with the exception of Fledermaus™, however Fledermaus™ files can be played with free iView4D software. Discovery Studio™ has the ability to play .cif file extensions. These files can be downloaded for free and used to create and view three-dimensional models of the molecular structures of minerals. Finally, audio and translation services were used to either record audio or for translation of one language to another.

Table 3. Examples of technology taught in the class or used in creation of the virtual tour.

Weekly Technological Category	Class Examples	
Online hard drives	• Office 365™	• Google Drive™
	• Dropbox™	
Presentation and screen casting software	• PowerPoint™	• Screencast-o-Matic™
	• Prezi™	• PowToon™
Interactive whiteboard apps	• Educreations™	• Explain Everything™
Visualization software	• World Wind™	• iView4D™
	• Google Earth™	• SketchUp™
	• Fledermaus™	• Discovery Studio™
Video editing software	• Cyberlink PowerDirector™	• Windows Media Maker™
	• iMovie™	
Audio and translation services	• Media.IO™ Audio Converter	• Babelfish™
	• Google Translate™	

4.2 Field Trip and Basis of Geologic Time: Teacher Workshops

K-8 teachers from the Texas Regional Collaborative were given links to online videos as part of a FLM experience prior to field trips with geologists. The instructional videos were created with free Educreations™ software. The videos were designed to show teachers that state mandated Earth science concepts can be taught locally. Figure 2 shows screen-grabs of examples of the videos teachers watched prior to field trips; specific content-based examples included the following:

1. Rock formations, pictures, and descriptions of formations teachers would encounter
2. Animated drawings showing the formation of El Paso’s Great Unconformity

3. Applicable teaching concepts which a focus on elementary and middle school, such as weathering, erosion, and ecological succession
4. Recent scientific observations and research such as recently discovered feeder vents to lava domes, and ash layers which will be used to distinguish ages of rock formations using radiometric isotopes
5. Caves, karst topography, and collapse structures
6. Faults and a major gravity slide

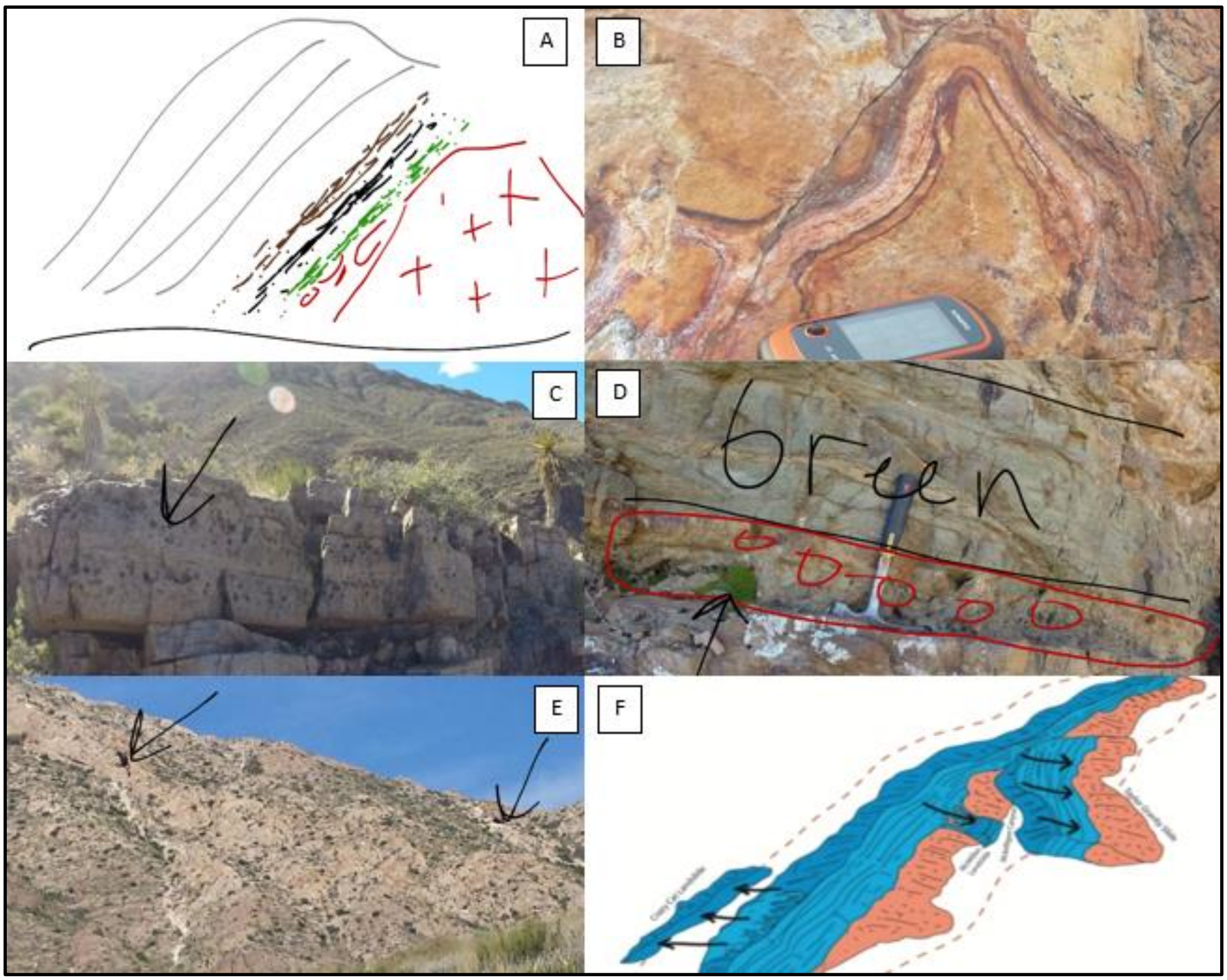


Figure 2. Screenshots from videos that were shown prior to field trips covering content such as A) an animation of how the Great Unconformity and related formations formed, B) weathering revealing liesegang banding, C) erosion, D) clastic dikes, E) karst topography and F) gravity slides photo credit Villalobos (2013).

These instructional videos used for teacher workshops are located at: http://alvarezanthony.weebly.com/ under the section titled "McKelligon Canyon Nature Series." The location where the class and workshops took place are separated by the Franklin Mountains, which teachers view on a daily basis. A method to put the concept of all time on Earth as a calendar year relative to nearby locations was required to provide an understanding of the vastness of time and identify, distinguish, and convey the relative ages of formations seen daily. In order to achieve this, a stratigraphic column is used. Stratigraphic columns can usually be found with little difficulty. Figure 3 shows the formations used in teacher workshops of the Texas Regional Collaborate.

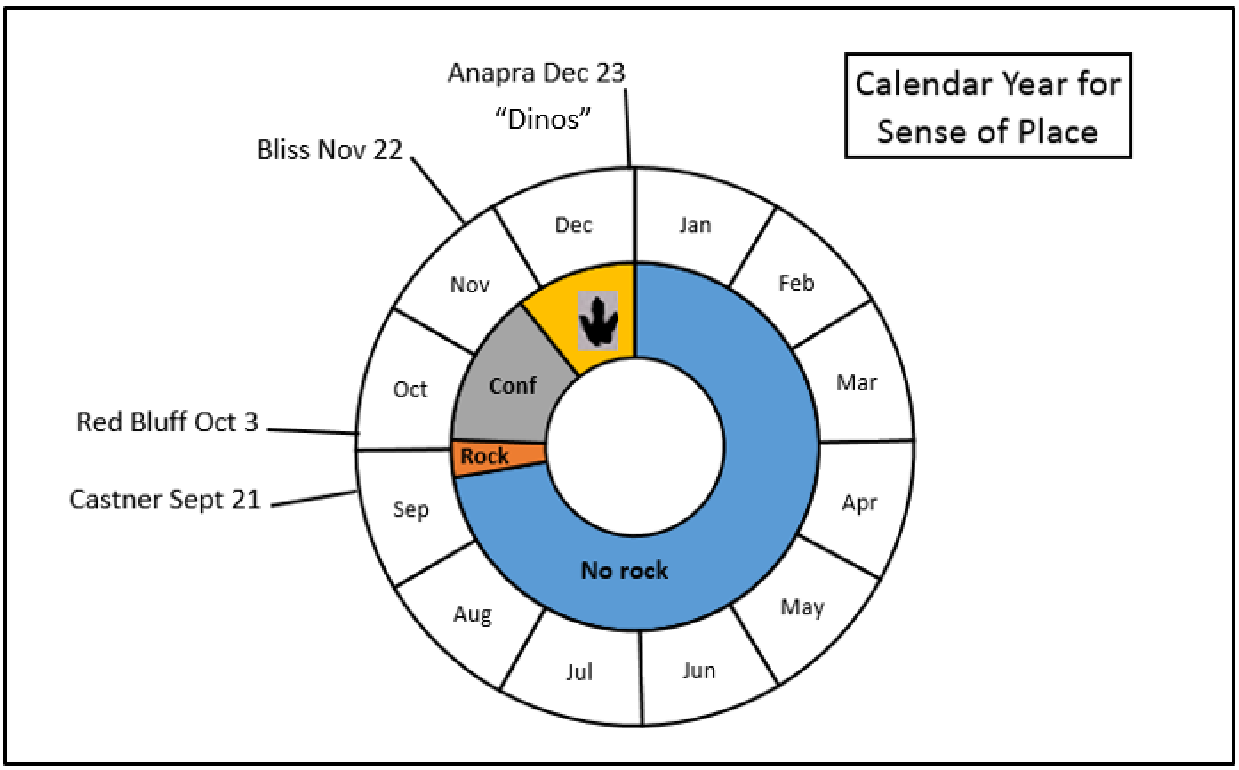


Figure 3. Displays when each formation was deposited relative to 365-day calendar.

In order to proportionally relate the ages of the rock formations relative to specific calendar dates a few basic ideas need to be established; first, Earth is ~4.6 billion years old and there are ~365 days within a year (not accounting for leap year). The quotient of these two numbers means

that when all time on Earth is compared to a calendar year, one day represents ~12.6 million years per day. Ages of rocks are characterized on stratigraphic columns by how many years have passed since the end of their formation. To figure out when rocks formed from the beginning of Earth, subtract the age of the rock formation from the total age of Earth. For example, the Castner Formation was deposited 1.27 Ga (Spencer et al. 2014); this yields 3.33 Ga. Meaning this unit formed ~3.33 billion years into Earth's existence. Based on how ages of rocks are reported, this model is counterintuitive to calculate the calendar date. With the age from the start of time established, divide this 3.3 Ga age, by ~12.6 billion years per day which is how many years each day represents. This is equal to approximately the 264th calendar day or September 21st as shown on Figure 3. This method was used to calculate the relative ages of rock formations viewed on field trips and to provide a clear understanding of the enormous amount of missing rock recorded by El Paso's Great Unconformity (Eg. Fig. 3).

5. Implementation

5.1 Virtual Tour: Graduate Class

The culmination of the Computer Applications class was using the provided materials to design the virtual tour. Each student in the class of teachers was responsible for describing one location. The VT was a means to combine all these individual videos into one overarching story. Through the duration of the course teachers learned the local geology and mastered the various technologies previously described. This provided the vital tools for the creation of the comprehensive VT presented here: http://prezi.com/nk4tdpxktt_p/

Creation of the virtual tour begins with an aerial photograph. There are a variety of "free" apps and programs that provide the ability to attain an aerial photograph; examples include NASA World Wind™, Google Earth™, Zoom Earth™, and Google Maps™ among others. The class

selected Google Earth^{TM} for its ability to easily georeference an image. Students inserted their selected aerial photograph into the Prezi^{TM} presentation software; this background image was used as the master map of the overall presentation (shown in Figure 4). Teachers from the graduate class provided precise geo-referenced locations where videos were to be embedded on the master map using latitude and longitude coordinates from Google Earth^{TM}. Thumb tack locations were inserted using Google Earth^{TM} at each student's individually assigned location. Students in the class were given individual time each week to consult with their instructors to validate progression in their geologic and technologic approach to teaching and describing their locale. Our goal was to clarify any lack of geologic detail and to help implement previously described technologies. Videos were created according to an assigned rubric. Necessary elements provided in the rubric were given percent values and averaged according to the rubric. Teachers were required to give general geography, geologic history, modern and prehistoric usage, and modern accessibility. Each video was then uploaded to YouTube^{TM} and the links to the YouTube^{TM} videos were embedded at the geographically accurate positions of the maps or images.

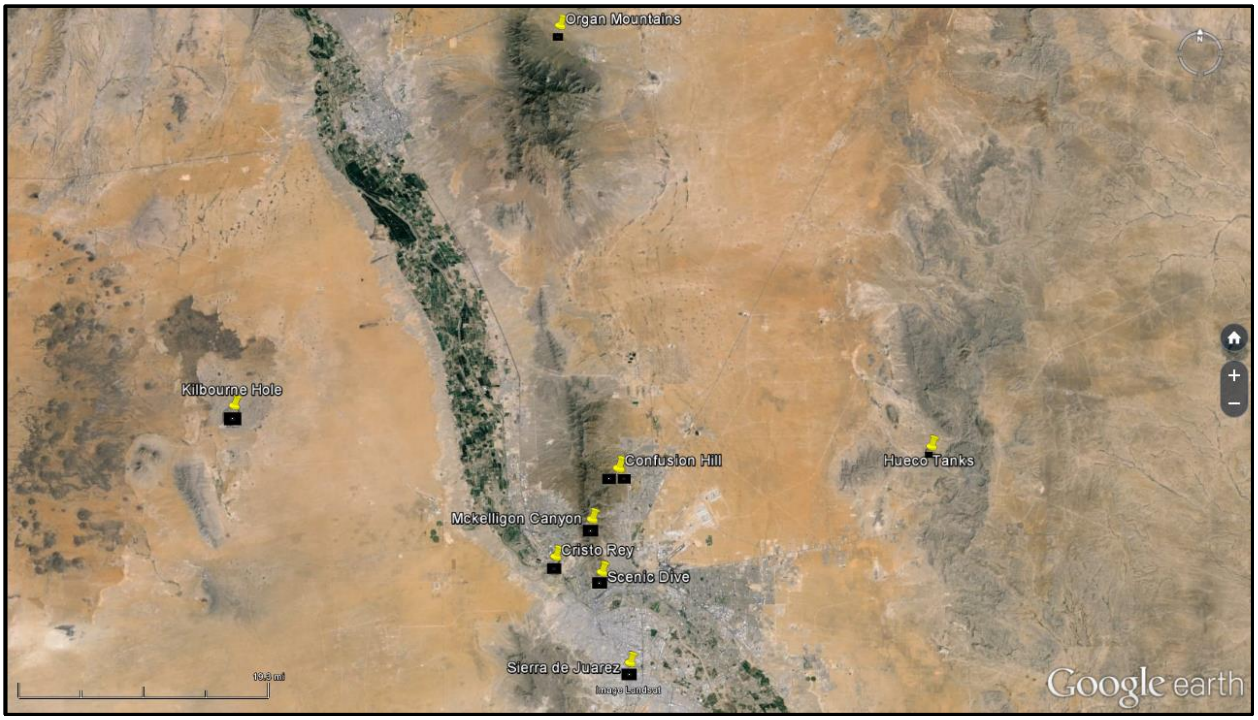


Figure 4. Interactive background of the virtual tour. The master map shows locations of embedded videos.

The embedded large scale images and videos were then organized into chronological order. This VT includes an introduction, scale, credits, a north arrow, and other essential elements all placed on the master map. After completion of the virtual tour, a user can click any location and instantly be taken to a video describing that location; if the user clicks sequentially through the VT, the tour will take the user in order from the oldest location to the youngest. Thus creating a geo-spatially and chronologically organized tour. Again the power of this presentation is that one is not locked into a chronological progression if one is otherwise inclined or interested.

5.2 Field Trip and Basis of Geologic Time: Teacher Workshops

During grant workshops, in-service teachers were brought to McKelligon Canyon in the center of El Paso's Franklin Mountains, and were shown El Paso's Great Unconformity (Figures 5a and b). El Paso's Great Unconformity represents a large time gap in the rock record and is represented by red lines in Figures 5a and 5b and the sector of the pie chart labeled "Conf" in

Figure 3. In Figure 5b teachers were shown that more than half a billion years of time is represented within a millimeter on the ground. Notice how difficult it is to distinguish between the two separate layers; this is due to some of the younger formation, above, being composed of grains from the older rock formation, below. During the field trip, teachers were shown two rock layers that have more than half a billion years of time missing between them, but just throwing out numbers did not make any of this missing time relative. Teachers were asked a simple question, what month of the year relative to all time on Earth does the oldest rock layer in this canyon (McKelligon Canyon) represent? Oral responses ranged from January to May, with most guesses in February and March. The age of the rock beneath the Great Unconformity in this canyon happens to be the Red Bluff Granitic Complex, which formed ~1.2 Ga years ago (Spencer et al. 2014). Using the method described above, this puts the oldest rock on the calendar day of October 3th, or five months further into a calendar year than anyone had assumed. Next, participants were told (again) that the missing rock, which had weathered and eroded away for more than 600 Ma, is the Bliss Formation known to be as old as the Cambrian Period, ~490 Ma (Repetski, 1982; Bellian et al., 2012). Participant teachers were then asked, "When on the calendar year (after October 3rd) would the next layer, the Bliss, represent?" Participants were not as responsive with oral responses due to being so far from the correct month for the Red Bluff Granitic Complex. There is only so much time remaining on the calendar after October 3rd. The relative date of the Bliss is November 22nd. This means the red line in Figures 5a and b, the missing rock record, represents 50 calendar days or ~13.7% of all time on Earth. This concept that El Paso's Great Unconformity is generally seen each day added to teacher's sense of place.

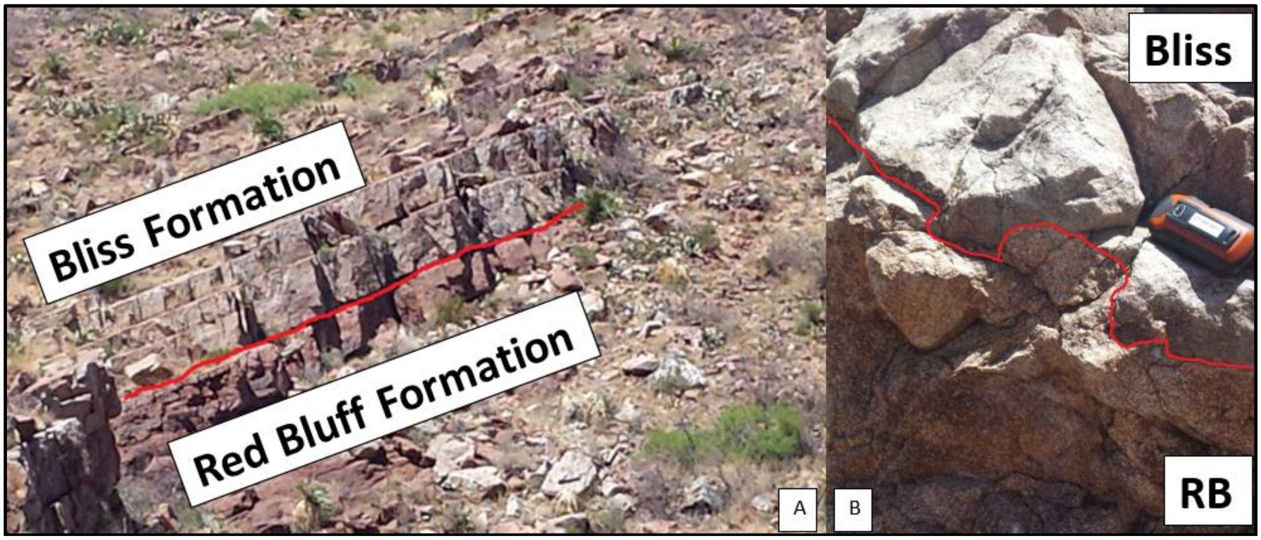


Figure 5. Images of the Great Unconformity showing A) from a distance and B) close-up. The red line indicates the Great Unconformity.

6. Evaluation

The two groups were unrelated so they were the measured using different methods.

6.1 Overall Design and Strategy Rubrics

The course requirements and resulting project grades for each student's individual video of an assigned area, based upon a location, while demonstrating a range of geologic time are listed below. Each of the elements above was given equal point value.

1. Teachers were required to say they are UTEP students and that their video represents a portion of the class project with the collective purpose to describe the billion year history of the area
2. All language had to be so that an average person can understand and to define words as necessary
3. There would be at a minimum a world map with a brief description of what the Earth looked like at that geologic time and an aerial map, which would define the geographic location in a student's own words
4. Current pictures of the area/location and rock formations with accompanying descriptions

5. History in the regional, geologic, and cultural context, meaning a description of the geologic processes describing rock formations, what happened to the formations over time, and any cultural significances
6. Additional content and figures to illustrate 2-5 and appropriate citations to credit deserved work

Pre- and posttests were given to the participants of the teacher workshop. The questions used in these tests are listed below; four of the questions asked for teacher's range of favorability from strongly agree to strongly disagree (1, 2, 4 and 5), two questions were multiple choice (7 and 8) and the rest of the questions were open-ended.

1. Would you recommend the site of the McKelligon Canyon Nature series videos to others?
2. The professional development via the combination of the videos and field trip virtual tour increased my interest about the local area
3. Do you see other applications for the technology presented? Explain:
4. Do you want to learn about a location using digital technology?
5. Digital representations helped me understand the processed that shaped the Franklin Mountains
6. Classify the processes that create the following rock types: igneous, sedimentary and metamorphic
7. What is the age of the oldest rock(s) in El Paso?
8. Of the 3 types of rocks, how many are found in the Franklin Mountains?
9. Describe your favorite and least favorite parts of the professional development (use the back of this page if necessary).

Discuss any Earth science-based concepts that were not covered through the instructional videos and field trips.

6.2 Methods

Teachers within the Computer Applications of Earth Science course were assigned to write a summary of what techniques, such as software, picture and video file extensions were used and created. They were also asked to discuss any specific problems that were encountered during the video creation. The videos were reviewed by the class, instructors, and there were class discussions after each video was previewed in-front of the class; video edits were made as necessary. Course and instructor summaries provided information as well as follow-up questions, in the form of email communications. The graduate course was co-taught by two instructors and one teaching assistant. The university distributes official course surveys on-line so students can take fill them out at their leisure. The university averages course reflections and makes sure all course comments are anonymous. The results are sent to the faculty of the course. Most feedback from the course was provided by the weekly one-on-one opportunities provided which allowed questions and feedback between the student and instructors.

For teacher workshops, coordinators provided areas of teacher weakness based on state, local, and regional state data. These were the topics that FLM videos, trainings, and field trips were focused on. Principals of schools and district science personnel also provided input from district to individual school needs. Assessments with content and survey questions were distributed by staff from the Texas Regional Collaborative Grant before and after professional development trainings which consisted of teacher trainings, workshops and field trips. Multiple choice, open-ended, and survey questions were analyzed by grant coordinators. Survey responses were assigned numbers from 1 to 5 in accordance to individual responses, where a value of 1

represented strongly disagree to a value of 5 for strongly agree. T-test analysis was used to calculate p values for survey and multiple choice questions. Informal assessments were provided by geologists that accompanied teachers on field trips. These informal assessments along with the pre and posttest data provided the grant coordinators with insightful knowledge as to areas of strengths and weaknesses for future professional development/trainings.

7. Results

7.1 Technology Course

The technology class showed improvement in knowledge and use of varied apps. Their knowledge of the regional history seemed to vastly improve. Here we will discuss some of the issues that were noticed by students and instructors during reviews of and class discussions of presented videos. While Spanish translations were not required, of those that included them, the translations were generally of poor quality. This issue arose from students allowing Youtube™ to add captions. A common issue with some videos was that presenters spoke too rapidly. Many presenters did not do a thorough job describing minerals located at their location and even though the class had experience creating three-dimensional molecular structures of minerals, from one of the class labs. None of the students incorporated this concept into their videos. This molecular modeling did require the use of Discovery Studio™ and similar viewing apps. This molecular modeling lab was one of the more complex labs, so it is understandable that this was not used, but it was disappointing that no one made the attempt. So, we can say that with a complex final project such as this video, required to encompass the total of the courses learned technological knowledge, it was more common for students to stick with more easily learned and manipulated techniques.

The reports of video techniques and problems encountered during video creation, which were required as a course grade, displayed specific struggles encountered during video creation. The

most common problem encountered was during attempts to embed Spanish subtitles, although some students described specific problems encountered during video creation. An example is "A problem I encountered with PowToon is that if you want to add a video to your movie it won't let you. If you try to add a video it will change it from movie to slides, so it is not a movie anymore and to go from one slide to another you have to click on the slide." Similar issues were observed with other video editing software, including Youtube™ uploads. Some of this could be written off to software usability, but is more likely a result of a general learning curve that occurs with the introduction to any new software.

Most of the class had a very little background knowledge in geology or the new technology, much of the students' knowledge was developed through the course of the class. Each individual student would research their location and present information to the class; other students could ask questions and the instructors would make comments and add or remove pertinent information weekly. Thus the whole course was building on the technological and historical knowledge of the students class by class. Further, there was a language barrier as several of the students lived in Mexico and attended class in the United States. A simple example of how this could be an issue is American vs. Spanish nomenclature of basic geologic terms. In the U.S. an intrusive dike is called just that, however, to a Mexican geologist such a formation is known as a, "clavo," or nail. Despite, such barriers, whether it was language or basic knowledge, the instructors are confident, much was learned. Evidenced both by the videos, the culminating VT, emails from students, individual commentary from students, and the anonymous reviews from UTEP.

Official course surveys showed students appreciated the ability to ask questions directly to instructors and the teaching assistant without being around their peers/classmates and individual one-on-one meetings with course instructors clarified many content-related misconceptions.

Ultimately 100% of the class rated the course as excellent and currently 20% of the graduate class now teach college courses including geology. One teacher said, “To this day...Your class has been the most influential class I have ever taken in regards to educational technology. I still incorporate all that we learned and for that I am grateful for all your work.”

7.2 Teacher Workshops

Teacher Workshops showed that speaking information to a student did not stick. However, after field trips and aforementioned relatable discussions information was seen to stick. Prior to professional development trainings facilitators of the Texas Regional Collaborative Grant did not provide much in terms of background information about participants or specific content areas to focus on. Therefore it was necessary to look at state-mandated knowledge and skills in the of student deficiencies. Due to the grant participants being instructors of elementary and middle school levels, finding appropriate horizontally aligned content to fit all needs was difficult. Formal and informal assessment and survey questions showed teachers had very little knowledge of local geologic concepts nor the ability to apply local Earth science based concepts in a classroom setting. Pretests showed teachers had a clear understanding of the processes that create the three main rock types, but were not knowledgeable about how many of these rock types appear in the local Franklin Mountains, the order of age of local rock formations, or how to utilize digital representations or images in order to teach Earth science based content. Comparison of pre and post content-based test scores showed significant gains in the number of rock types that appear in the Franklin Mountains (p-value .047) and the magnitude of ages of local rock formations (p-value .02). Unfortunately, p values did not increase with respect to how to use digital representations to understand the processes that shaped the Franklin Mountains, or interest in the local area. Results

for the teacher workshops are displayed in Figure 6, which show the specific areas in which significant changes did and did not occur.

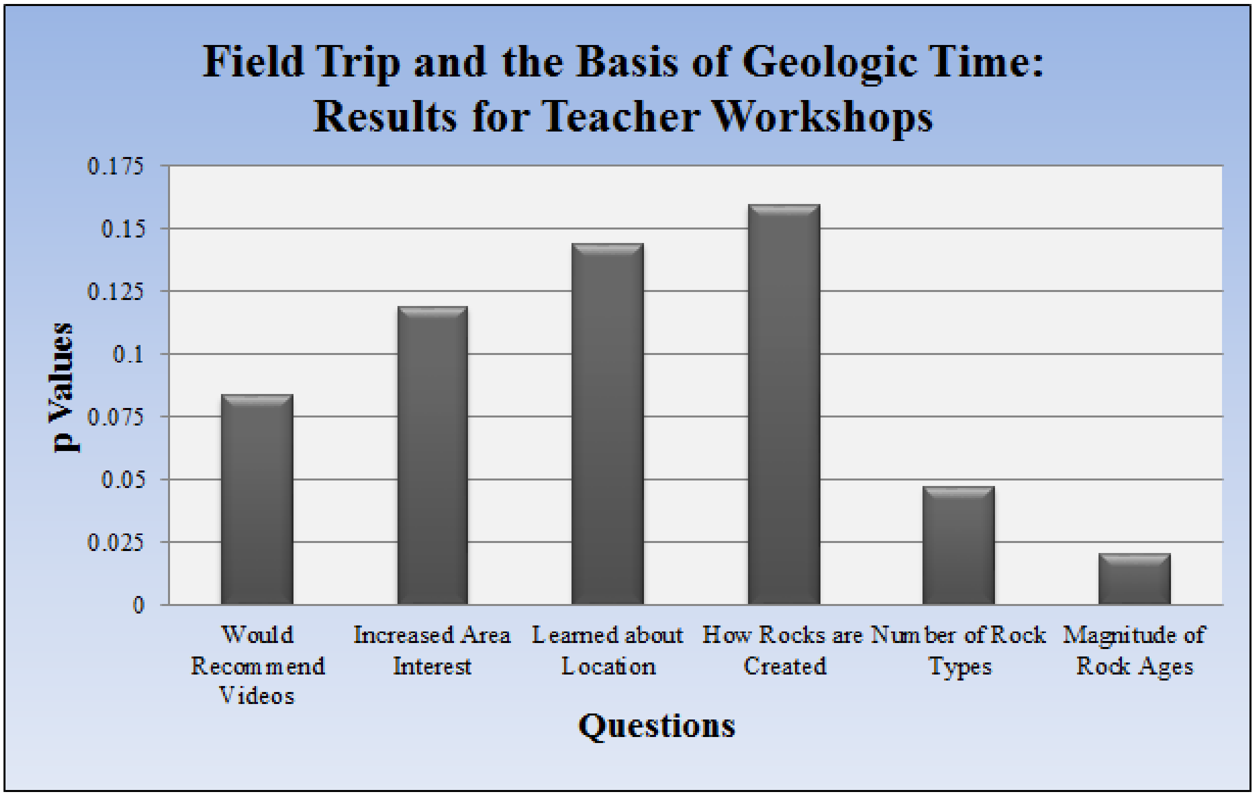


Figure 6. Shows the results of pretests compared to posttests for teacher workshops.

8. Limitations

Obstacles were encountered in teaching the vastness of time. Insufficient basic knowledge of Earth science content from students and teachers was a common issue. This was not surprising considering the different cultures and required learning based on our location on an international border with many Spanish and English language learners of varied educational backgrounds. English was not the first language of everyone in the class, and additional help and support was sought out from professors beyond those assigned to the class. This illustrates the need for a common formulation of descriptions of different locales into a technological medium that represents the billion year geologic history of the El Paso/Juarez area. This conceptual idea could be applied to any area with a complex geologic history. Areas with a less complex geologic history,

such as New Orleans, where the local geology consists of flat laying layers of mud and sand, would be able to use this virtual tour for any level of educational learning which covers the history of Earth. Each video shows tectonic/continental changes to the U.S. at various times; these videos can be related to different educational needs, such as basic historical geology, sedimentology, and tectonic history. Assessments in technology and content knowledge were easier to assess than methods learned in pedagogical knowledge. Videos were peer-reviewed by classmates and course instructors before they were due. At that time any errors or misconceptions required the videos to be corrected and resubmitted.

9. Implications

Video creation is common and often required for students at middle school and high school levels. The technological knowledge needed in order to create a virtual tour described here is no greater than the knowledge required to create a video and a PowerPoint^{TM} presentation. Teachers are very much behind the curve in regard to their students being more capable digital natives. Digital natives enjoy learning through videos that show animations, highlights, pictures and audio. It is uncommon to find students learning from textbooks; even now, textbooks are including more online content, FLM videos and materials. Teachers from the graduate class were not told/shown how the geologic formations formed, there were deductions and conclusions that had to be individually made. Examples of challenging localities to describe include: landslide deposits, the series of events that lead to mantle on the surface of the Earth and recumbent folds. Teachers used their unique teaching styles, connectivism, constructionism, and a sense of place to describe each location's past and current cultural influences. An example of a cultural influence would be Mt. Cristo Rey. For geologists there was a laccolith, faults and folds, various ages of fossils including the largest oyster ever observed in the fossil record, dinosaur tracks and more. Culturally, Mt.

Cristo Rey on several occasions each year is a site of spiritual pilgrimages to the 29 ft. statue of Christ on the top. A common occurrence is for individuals to make the voyage barefoot or on one's knees; this is done for repentance.

The learning opportunities provided were good because the students that lived in Mexico were able to provide the class with geological, cultural and place-based examples that students on this side of the border were unfamiliar with. In many ways the virtual tour is an example of a cultural-TPACK, first described by Jupit and others (2012). In order to unravel the series of events at a locality and to integrate technological, pedagogical, cultural, and content knowledge required higher-order thinking. An example of this was a teacher which created a model to replicate the formation of a lake. Teachers had to decide which technology was going to be used to describe the content, record audio and video and upload it to the internet. Pedagogical skills used are included in what approach will be used to teach the content. The graduate class was taken to the location of a landslide deposit shown in Figure 1b. At this point in the class students had tried and practiced several types of video creation software. The class was then asked to interpret the outcrop, and there were some surprising results. There were many interesting approaches the class used to teach the outcrop, but there were two individual videos that stood out the most. In the first video, a teacher started with a blank canvas and described from the various formations from oldest to youngest as this teacher drew in formations one-by-on and explained each while showing field examples and photographs of each. In the second video, a teacher started on one end of the outcrop and walked the length of the outcrop and described what the observer would see from one end to-the-other, showing pictures of what the observer would see as the outcrop was traversed. The outcome of their student-centric collaboration of place-based localities was a product that can be used as an instructional instrument for a diverse range of educational environments.

The main goal of both groups was to teach not only the relative vastness of time but to impart methods to teach this concept. An increase in teacher knowledge and place-based knowledge would then impact current and future students. Pre- and posttests showed a significant change in the comprehensive knowledge of the magnitude of ages of local rock units for the teachers within the workshop, which was the main goal. For this group, there seemed to be a considerable amount of interest in using the instructional videos demonstrated to the teachers in the workshop based upon volume of email requests, comments and questions, unfortunately pre- and posttests showed no significant change in interest. While the groups learned the content of the course and workshops, we could also see how their pedagogical knowledge using the desired teaching techniques of connectivism, constructivism, and sense of place improved.

Chapter 4: Mathematical Concepts Utilizing Google Earth

Abstract

Current trends show students are losing interest, confidence, and engagement in their abilities in mathematics and science at alarming rates. We as educators are not conveying and connecting concepts in meaningful and relatable ways. Visualizing spatial relationships is a crucial skill to help students stay in and succeed in STEM-related fields. Google Earth™ is geospatial visualization program that gives students the opportunity to look at any corner of the globe, but there needs to be better mathematical approaches utilizing Google Earth past the primary grade levels. Exercises outlined in this report will help students understand essential mathematical concepts using Google Earth, such as the slope of a path that is frequently traveled or how to create an equation of a line for a familiar place. This paper also demonstrates methods to create and solve problems related to dilation, the Pythagorean Theorem, and a new technique for creating and manipulating polygons to find the volume and surface area of geometric shapes.

1. Introduction

Geographic Information Systems (GIS) have helped geospatially organize information dating back to the 1830s and 1850s with Charles Picquet and John Snow respectively (Jangra et al., 2013). At those times GIS was used to interpret patterns of cholera outbreaks, but as society evolves, so do the methods to express, learn, teach, and organize information. Unfortunately, the methods used in classrooms are not able to keep students engaged. The Trends in International Mathematics and Science Study (Mullis et al., 2012) is a comparative study of science and mathematics achievements of fourth and eighth grade students in 63 countries. This study concluded that between the 4th and 8th grades, students in the United States lose interest,

engagement, and confidence in their math and science abilities (Martin et al., 2012; Mullis et al., 2012). New methods to teach mathematics and science are needed especially spatial relations. Ormand and others (2014) report visualizing spatial relationships, such as objects, are a fundamental skill to communicate efficiently in STEM fields as concluded from both long-term and small-scale studies. A review and analysis from Uttal and Cohen (2012) state that spatial abilities make an essential difference by increasing the number of individuals who are cognitively able to succeed in STEM fields.

Google Earth™ (GE) is a virtual globe, and a means to help understand and interpret spatial relationships. Zhu and others (2014) report that GE files (KML) are becoming an international standard and a means to represent, publish and exchange information. Methods of incorporating GE into the classroom are continually changing. Benjes et al. (2012) and Johnson et al. (2011) discuss examples of GE in content areas such as social studies, Earth science, foreign language, astronomy, and English among others. There are even websites dedicated exclusively to classroom activities in GE, such as serc.carleton.edu/sp/library/google_earth/activities.html, realworldmath.org, and googlearth.weebly.com to name a few. There are numerous classroom activities related to Google Earth; unfortunately, few relate to mathematics. The types of math problems associated with GE are used to find the perimeter and area of squares and rectangles, but on the 2016 exam for eighth grade students in Texas, only 1 out of the 56 questions covered these topics (STAAR Released). The most frequently tested items were related to linear equations, the volume of geometric shapes and the Pythagorean Theorem; this report will give specific examples of how students can utilize GE for these commonly tested topics.

2. Methods

2.1 Slope and Linear Equations of Frequent Paths

The most frequently tested topics for 8th graders in the state of Texas are related to slope and linear equations (STAAR Released). Linear equations and slopes have no relevance to students, no connection, but if students can calculate paths they traverse daily it would make these concepts more pertinent. In this example, GE is used to determine which commonly walked paths on the campus of The University of Texas at El Paso has a higher slope. The first trail is called Cardiac Hill, the second track, just up the street, is called Glory Road. These are local, culturally relevant names for these places, used and passed down by university students. The first step is to insert thumbtacks. Use the thumbtack icon at the top of the screen at locations of familiarity. After adding thumbtacks, distribute the GE file with students. Google Earth files can be easily shared and distributed, especially with so many options to create free websites; examples would include: weebly.com or wix.com. Links from online hard drives can also be shared; examples include Google Drive™ and Dropbox™.

After sharing a GE file, students will open the file and have access to the same information and elements; after the program is opened change the units to meters. To convert units, select Tools then (in the pull-down window) click on Options. A new window will open and under Units of Measurement choose Meters. Next, on the left-hand side, there are three different tabs: Search, Places, and Layers. Under Temporary Places click the little "+" icon; this will open the elements for students to see. In this example, students will click on the component titled Cardiac Hill. Google Earth will then take students to the view shown in Figure 1A. The next step is to move the mouse over one of the tabs to view the information shown in Figure 1B. The information displayed at the bottom-center of the screen includes Longitude, Latitude, and Elevation in meters.

Figure 1. Google Earth screenshot showing A) desired beginning and end points of a trail on which slope is to be determined, and B) the information available when the cursor hovers over a thumbtack or any location.

With the cursor find the elevations of these two points. The difference between these two numbers will be your change in height, graphically/mathematically this will be annotated as ΔY; remember slope (m) = ΔY/ΔX. The next step is to calculate the ΔX. The change in X is the distance on the map from one tab to another. At the top of the screen there is a ruler icon, click the image, and a new window will open, then change the units to meters. Next, click on the point of one thumbtack and move the cursor to the other. Figure 8C shows the options under the ruler icon. The ruler measures the horizontal distance or ΔX. Dividing ΔY by ΔX gives the slope (see Figure 3A). Another method for not only calculating but also visualizing and graphing the gradient is first to create a path. The path icon is at the top of the screen and is represented by three dots. After clicking on the path icon, click on the points of both thumbtacks and give the path a name. The path is now in Places on the left-hand side of the program. Right-click on the created track then select Show Elevation Profile; Figure 2 is an example of an elevation profile.

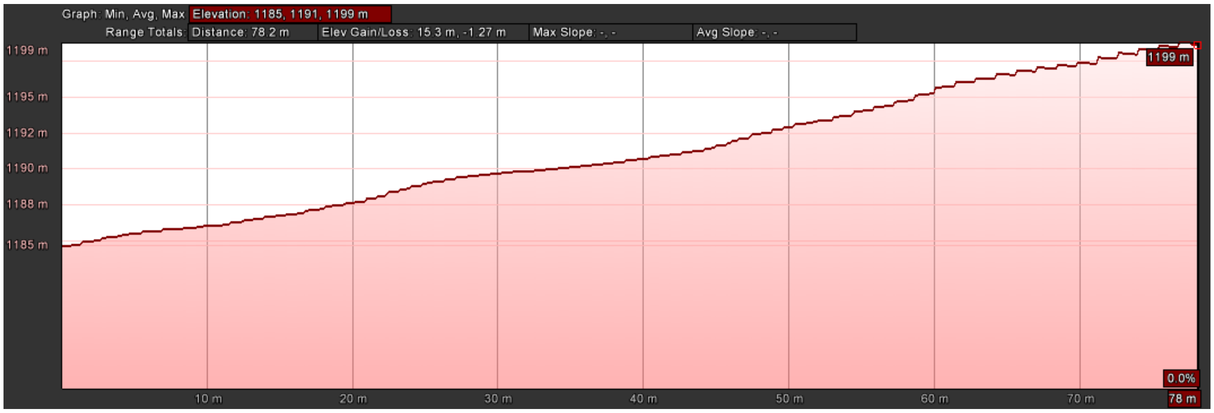


Figure 2. Elevation profile created with a path in Google Earth showing, ΔY is 14m, ΔX is 78m, and the slope is 7/39.

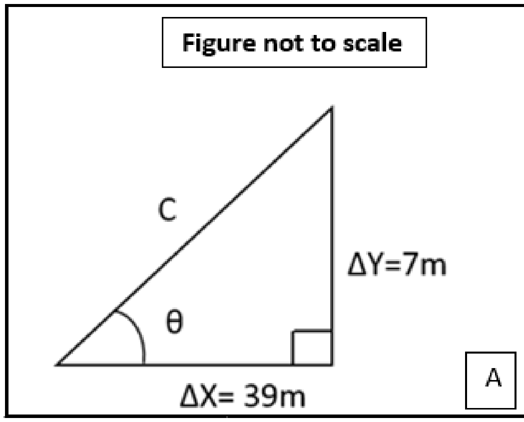
The process of finding slope can be repeated to determine which path has a higher slope. Using the elevation profile above you can select a point and use the point-slope formula ($y - Y_1 = m(x - X_1)$) to solve for the equation of a line (shown in Figure 3B). Two points selected from the elevation profile in Figure 2 are (0, 1185) and (78, 1199). The equation of the line can be written in the standard form ($Ax + By=C$) or point-slope ($y=mx + b$). Figure 3B shows the equation of Cardiac Hill. Students are now able to solve for places they go every day or locations that have traveled to in the past, making the lines and slopes individually relevant. The gradient of Glory Road is 9/59, and the equation of the line is $y= (9/59)x +1169$. Once the linear equation of both triangles is known, this would be an excellent opportunity to solve for a system using the addition or elimination method (Figure 3C). The point where these two lines intersect is in Figure 3C.

To solve for slope:	**To solve for linear equation:**	**To solve for the system of equations:**
Points: (0, 1185) and (78, 1199) $m = (Y_2-Y_1)/(X_s-X_1)$ m = (1199-1185)/(78-0) m = 14/78 = 7/39 A	$(y - Y_1 = m(x - X_1))$ y-1185 = 7/39(x-0) y = (7/39)x +1185 B	$Y_1 = (7/39)x +1185$ $Y_2 = (9/59)x +1169$ y = (7/39)x +1185 = (9/59)x +1169 x ~ -593.8; y ~ 1,259.6 C

Figure 3. Computations showing how to solve for A) slope B) linear equation and C) system.

2.2 Dilation and Pythagorean Theorem

After using the method above to calculate the ΔY and ΔX. The next step is to use the Pythagorean Theorem to solve for the hypotenuse of the unknown side of the triangle, as shown in Figure 4A. Adding all three sides of the triangle gives the perimeter. With the length measurements of the right triangle known, trigonometric identities can now be applied to solve for any angle. Figure 4B shows the methods to solve for the hypotenuse and θ.



Pythagorean Theorem

$C^2 = \Delta Y^2 + \Delta X^2$

$C = \sqrt{(\Delta Y^2 + \Delta X^2)}$ the square root of $(\Delta Y^2 + \Delta X^2)$

$C = \sqrt{(1570)}$

$C = 39.6m$

Trigonometric Identity

$Tan\theta = opp/adj$

$\theta = Tan^{-1}(\Delta Y / \Delta X)$

$Tan^{-1}(7/39) = 10.2^{\circ}$

B

Figure 4. Shows A) right-triangle B) calculations of the hypotenuse and θ.

Another commonly tested topic in 8^{th} grade is dilation. Dilation is when you have two similar objects that are different in size, but not in proportion. The triangles in this exercise are not the same shape, but we are going to continue as if they are. By dividing ΔY_1 by the smaller ΔY_2, this gives scale factor of the triangles created by Cardiac Hill and Glory Road, as shown in Figure 5B, which is approximately 1.5. Google Earth™ has been used to relate map scale and proportionality (Roberge & Cooper, 2010).

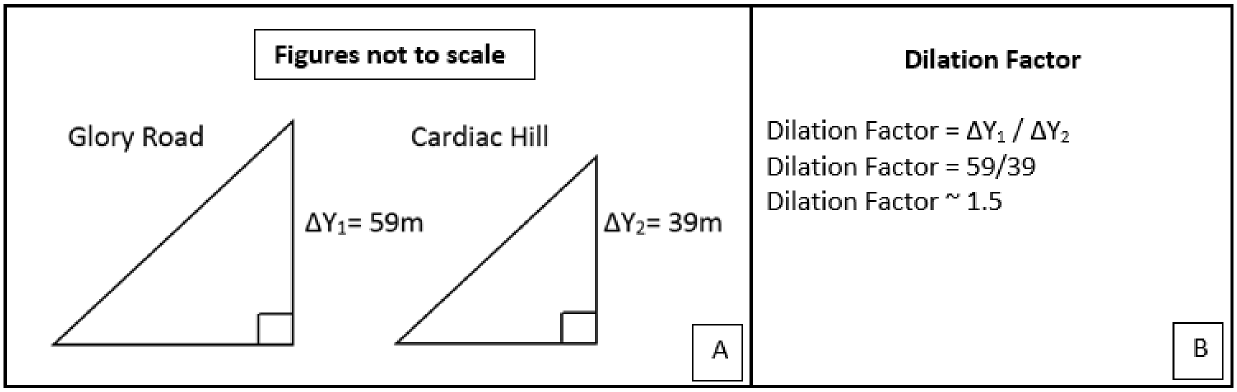


Figure 5. Shows A) ΔY_1 and $\Delta Y2$ of the known paths and B) calculation of a dilation factor.

2.3 Volume and Surface Area of Geometric Shapes

On the 8th grade mathematics exam, students in the state of Texas have to answer questions related to the volumes of geometric shapes, such as triangular and rectangular prisms, cylinders, cones and spheres (STAAR Released). Conceptualizing 3-dimensional figures can be difficult. GE has been used in previous examples to measure area and perimeter. The ruler icon measures distance within the program. The area and perimeter are displayed during the creation of a polygon. After clicking on the ruler, select the desired unit. After the 1st and 2nd-dimensional measurements of perimeter and area are completed, the next step is to measure height, which is used to solve for the 3rd dimension. Select the polygon icon and click on the area around the base of the object that the height is to be measured (in this case it would be the four corners). Problems will arise if the "3D Buildings" is not checked under Layers.

After a polygon is created and given a name, the polygon can be seen/edited under the current places on the left-hand window. Right-click on the name of the generated polygon and then select Properties. Under Properties, there are four tabs. Click on the Altitude tab. The default setting in the pull-down menu is "Fixed to Ground." Change this setting to "Relative to Ground." The polygon can now be raised to various heights. Make sure you have the desired units selected.

There is a slider-bar for the height, and after using the slider-bar, the up and down arrows on the keyboard can be used to elevate the polygon. Once the polygon is above the height of the figure, the entire polygon is viewable, and the window will display the height in the desired units. The example used in Figure 6 measures the height of the Great Pyramid of Giza. Figures 6A-D show a bird's-eye view (plan view); Figures 6E-H show cross-sectional views of a polygon at the heights of 0m, 50m, 100m, and 150m. Figure 8A shows the volume calculations. This method works on other geometric shapes, such as cylinders, with the Leaning Tower of Pisa and spheres, such as the Epcot Center in Disneyland.

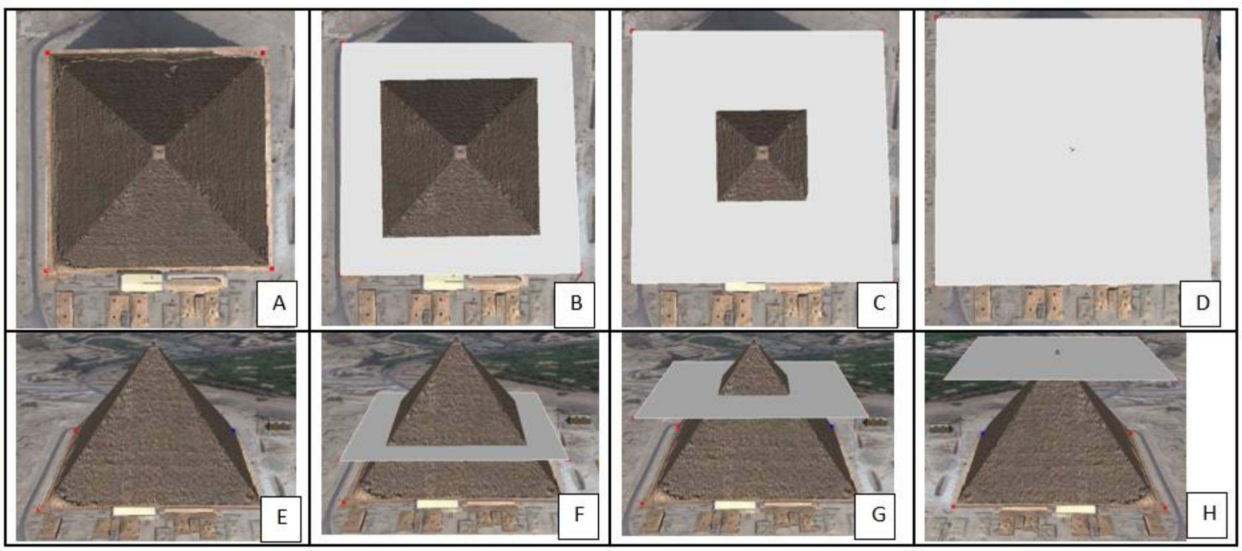


Figure 6. The Great Pyramid of Giza with a polygon raised to the heights of 0m (A/E), 50m (B/F), 100m (C/G) and 150m (D/H). This method is used to calculate the height of objects within GE.

This method can also be used to solve for lateral and total surface area, which are also tested topics on the 8th grade exam in Texas (STAAR Released). Students need to solve for the lateral and total surface area of shapes such as rectangular and triangular prisms and cylinders. Figure 7 shows the Komtar Tower in Penang, Malaysia. Figure 7A shows the base of the cylinder starts at 20m, and Figure 7B shows the height of the tower measures 243m and Figure 7C shows

the ruler icon measuring an approximate radius of 47.92m. Figure 8B shows the calculations for the lateral surface area, and Figure 8C shows the total surface area. Another example of a cylindrical building to solve for volume or surface area would be the Floreasca City Sky Tower in Bucharest Romania. An excellent example of a triangular prism to solve for the lateral and total surface area is the Flatiron Building in New York City, and a good example of a cone-shaped building is the Cathedral of Maringá in Paraná Brazil.

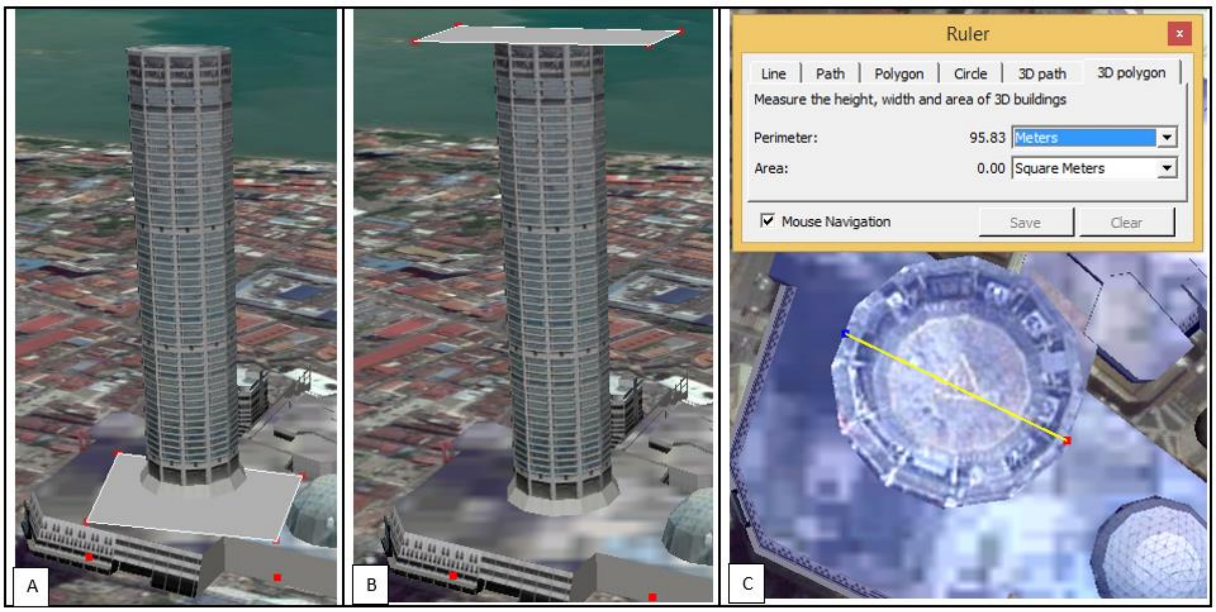


Figure 7. Estimations of A-B) the height and C) the radius being estimated of the Komter Tower in Penang Malaysia to calculate volume, lateral surface area, or total surface area.

Volume of a Pyramid	**Lateral Surface Area of Cylinder**	**Total Surface Area of Cylinder**
V = (1/3)B(h) *B= Area of base	LA = 2π(r)h h = 243-20 = 223m	SA = 2π(r)h + 2π(r)^2
V = (1/3)S^2(h) Side =229.65m	LA = 2π(47.92)223 r=47.92m	SA = 2π(47.92)223 + 2π(47.9)^2
V = (1/3)229.65^2(150)	LA ~ 67,143m^2	SA ~ 81,571m^2
V ~ 2,636,956m^3 A	B	C

Figure 8. Calculations of A) volume, B) lateral surface area, and C) total surface area.

3. Conclusions

Google Earth has numerous mathematical applications. Examples listed in this report include slope, equations of a line, systems of equations, Pythagorean Theorem, dilation, perimeter,

lateral and total surface area, and volume and trigonometric identities. Students may have difficulty relating to topics such as slope and linear equations, but if they can connect it to familiar paths or places they usually traverse, then there is an opportunity to make connections. Using GE, students can get a better sense-of-place of the land around them, specifically from the slopes they walk to the volume of the places they are familiar with, such as the school or the mall.

Chapter 5: Systematic Approach to Motion Analysis

Abstract

After more than a decade of debate, revision and practice a fundamental theoretical framework that unifies technology, pedagogy and content knowledge (TPACK) has been proven and established. The method described here not only describes a practical and methodological approach of incorporating motion analysis-based software within it classroom, it also provides impactful and relevant approaches wherein integrating mathematical and science-based content within TPACK, advancing the framework and creating a technological, pedagogical and *integrated* content knowledge TPICK.

1. Introduction

Society has reached a point where technology can open so many doors to understandings of mathematics and science, but what is "science?" The definition of science is simply how the world around us is interpreted. Within one generation technology has dramatically increased the ability to create and communicate these interpretations. A generation ago teachers would try to teach motion concepts, such as speed, by handing students a meter stick, a toy car and a stopwatch. The teacher would then expect students to accurately record the distance and time a toy car had traveled in order to calculate the speed/velocity. Why would students care how fast a little toy car is going? Students are more interested in finding out how fast they can run, how far they can jump, the speed they throw a football or kick a soccer ball. These make concepts such as speed, force, work, slope or linear equations individually relevant to each student. Table 4 outlines specific examples of technologies that possess the ability to answer these questions and instances of classroom utilization.

Table 4. Classroom examples of software to analyze motion.

Motion Analysis Software	Examples of Classroom Activities
Digi-Net	Chow et al., 2000
Logger Pro	Milner-Bolotin et al., 2007; Milner-Bolotin & Moll 2008; Moll & Milner-Bolotin 2009; Oldknow 2009 and Wyrembeck 2009
Measurement-in-Motion	Cappo & Darling 1996
Physics Toolkit	**Previously called World-in-Motion*
Tracker	Brown & Cox 2009; Wee et al., 2012; Rodrigues & Carvalho 2013 and Wee et al., 2015
VideoPoint	Laws & Pfister 1998 and Bryan 2005
Vidshell	Oldknow 2009

In order to perform these calculations, a program called Logger Pro™ (LP) is demonstrated. This software can be utilized to solve for variables such as temperature, light, pH, motion and more. All that is required for motion analysis is the LP software (or app), a camera and a meter stick. Recent research shows interactive learning experiments can improve students understanding of physics concepts (Moll & Milner-Bolotin 2009) and there is even evidence that students learn kinematics concepts more effectively than in non-interactive lessons (Wee, Tan, Leong & Tan 2015), but before students can be set free with interactive-based analysis there has to be several obstacles to overcome first. The steps outlined include:

1) Engage the students (schema).
2) Remind students they will have the opportunity to individually create something they can take ownership of (constructionism)
3) Teach the mathematical and scientific concepts they will need, such as graphical analysis, Cartesian coordinates, slope, linear equations, velocity, acceleration, work and force (background knowledge).

Provide hands-on opportunity to familiarize themselves with the software (tools and practice).

Figure 1. Student jumping off the roof.

2. Background Information

2.1 Engagement

The 5E model is commonly used method for teaching and learning new content; the first "E" of the 5E model is to engage. If students are not "hooked" immediately then you (as an educator) will lose their interest. Explain to students that no one is interested in seeing how fast a toy car can travel, you (as an educator) need to show students what's in it for them. Figure 1 shows a student jumping off the roof of the school. The engage you use does not have to be this dramatic, but it should be memorable.

2.2 Constructionism

Papert (1986) defined constructionism as two fold. First, that learning is more than a transmission of knowledge; students need reconstruct knowledge within their own minds and second, that students learn considerably when they make something they (themselves) can be

proud of. The important thing is to remind students that the data, graphs, tables and analyses created is going to be individually related to something they can take ownership in. Constructionism is similar to constructivism in that it is student-based and therefore students are in-charge of their own learning.

2.3 Content Knowledge

A theoretical framework has emerged which combines technological, pedagogical and content knowledge (Niess 2005; Mishra & Kohler 2006), but it took many revisions and alterations to get the theoretical framework to where it is. The first author to define the gap between actual student knowledge and the knowledge needed to comprehend a concept (under guidance) was Vygotsky (1978). Vygotsky mentioned the need to close this distance and ultimately have students achieve greater independence, through scaffolding. Scaffolding is incorporating a variety of instructional techniques to get students to greater comprehension and less dependence. Shulman (1987) stated that teacher knowledge should consist of a learner's community and culture, something TPACK has since moved away from. Chigeza and Jackson (2012) suggested language and culture must be present within the TPACK framework. Jupit, Minoi, Arnab & Wee (2012) agreed and proposed a culturally-based content as a Cu-TPACK or cultural TPACK. Skemp (1976), Kinach (2002) and Shulman (1987) all had a part in influencing the framework through defining learners via subject and pedagogical content knowledge. The TPACK framework still has room to improve. This report adds the idea to integrate content knowledge, in this case, mathematical and science-based content within the established TPACK framework, creating a technological, pedagogical and integrated content knowledge.

C

	Time (s)	X (m)
1	8.667	0
2	8.700	-0.05529
3	8.733	-0.1327
4	8.767	-0.2986
5	8.800	-0.6082
6	8.833	-0.9289
7	8.867	-1.371
8	8.900	-1.747
9	8.933	-2.145
10	8.967	-2.610
11	9.000	-3.041
12	9.033	-3.395
13	9.067	-3.671
14	9.100	-3.992
15	9.133	-4.247
16	9.167	-4.468
17	9.200	-4.722
18	9.233	-4.965
19	9.267	-5.231
20	9.300	-5.441

Figure 2. Logger Pro analysis showing A) select frames of a jump, B) origin and scale, and C) data.

3. Methods

3.1 Cartesian Coordinates, Average Speed and Dimensional Analysis

Figure 2 shows a video of a student doing the long jump as presented to the class. The class is then asked to give an estimate in feet of the distance the student jumped. The video is shown one more time so students can give their best estimate. After all students write down their individual estimates on the board, the class has a moment to reflect on the estimates; for example, the class can see the highest and lowest estimates and any outliers. The class is then shown how easy it is to determine the distance, but before the class can determine the distance the class is shown an x-axis and a y-axis and asked which one is which? The question is then posed, “Are we seeing how high the student is jumping or how far the student is jumping i.e. are we measuring distance in the x-direction or in the y-direction?” After students conclude that distance is to be measured in the x-direction, a diagram is then drawn on the board showing the student jumping from right to left, and the class is then asked if this is ‘x’ in the positive direction or in the negative

direction? The class is also shown how to set a scale and how to set the location of the origin, in this case it is

$$\left(\frac{5.441\,\text{m}}{1}\right)\left(\frac{3.28084}{1\text{m}}\right) = 17.85\ \text{ft} \qquad \text{A}$$

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}} = \frac{5.441\ \text{m}}{(9.300\text{-}8.667\text{s})} = \frac{5.441\ \text{m}}{0.633\ \text{s}} = 8.6\ \text{m/s} \qquad \text{B}$$

Figure 3. Calculations of A) conversion of units from meters to feet and B) average speed.

3.2 Graphical Analyses

Now that the x-and-y axes are established, then next crucial topic is graphical interpretation. The ability to read graphs is important in all content areas, especially mathematics and science. Graphical analysis is demonstrated with an example of projectile motion. Classroom activities utilizing motion analysis software with projectile motion include Laws and Pfister (1998), Chow, Carlton, Ekkekakis & Hay (2000) and Rodriguez and Carvalho (2013) even used the game Angry Birds™ as an example. Figure 4 shows a student shooting a basketball, the origin was set at where the student was prior to shooting the basketball. Logger Pro is then used to create distance vs. time graphs and speed vs. time graphs shown in Figure 5. Figure 5A shows distance vs. time in both x and y directions. The graph of X (in meters) vs. time is fairly linear (m >0 positive) as time progresses; the basketball travels ~4.3 m in the X direction in .9s. Figure 5A also shows the graph of Y (in meters) vs. time. The graph is quadratic (same as the path of the basketball) with the vertex at the position where height is neither really increasing nor decreasing just past the 3.9 s mark. The height starts at 2.035 m (just above the student's head) and reaches a maximum of 3.614 m vertex and stops at the rim of the court ~3 m above the ground. Figure 5B shows the graphs of speed in both the x and y directions vs. time. The graph displaying speed in

the x-direction is represented by triangles and is fairly linear; where (m~0) with no slope. The line represents the speed of the basketball in the X direction which maintains a speed relatively close to 4.6 m/s. The graph displaying speed in the y-direction is represented by diamonds and is also equally linear ($m<0$), after 3.9 s the ball is on the way down and the values for Y become negative because the ball is traveling downward. The graph shows the speed cross the x-axis (or zero) because when the ball reaches the apex, it is not traveling up or down at that moment. Figure 5C displays the raw data.

3.3 Slope and Linear Equations

With the data established for projectile motion in Figure 5C this opens the door for various mathematical and science-based content. A common concept necessary for both domains is rate of change, also known as slope. Using the movement in the y-direction before apex at times 3.7 and 3.933s, the points (3.7, 3.281) and (3.933, 3.614) are established. Figure 6A shows the steps to solve for the slope, and Figure 6B displays how point-slope formula is used to solve for the linear equation.

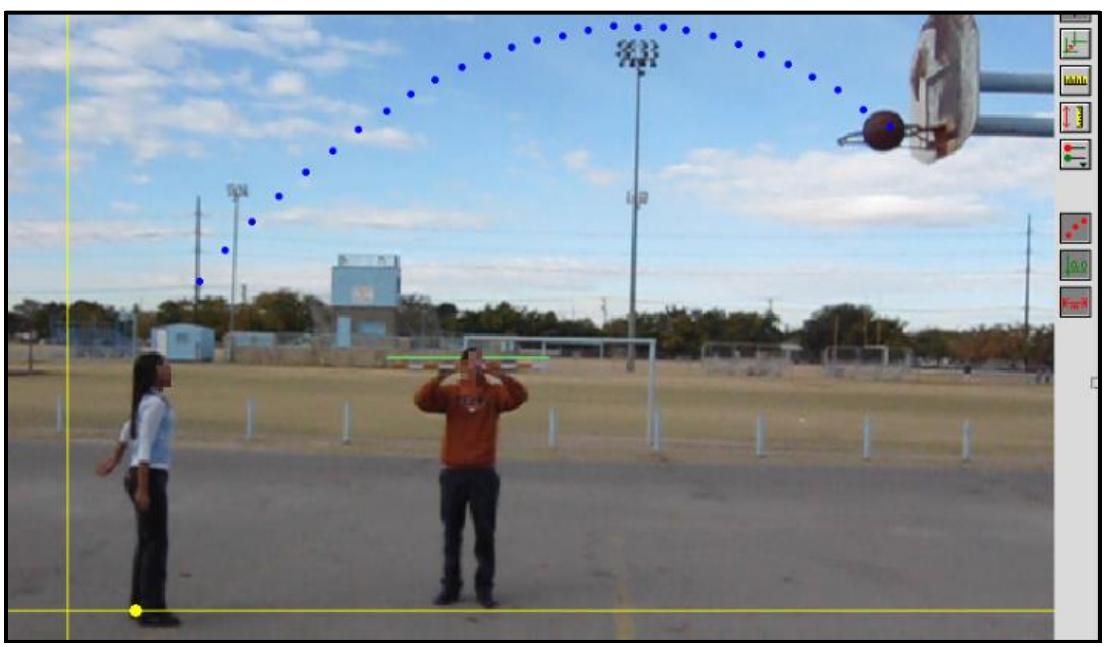
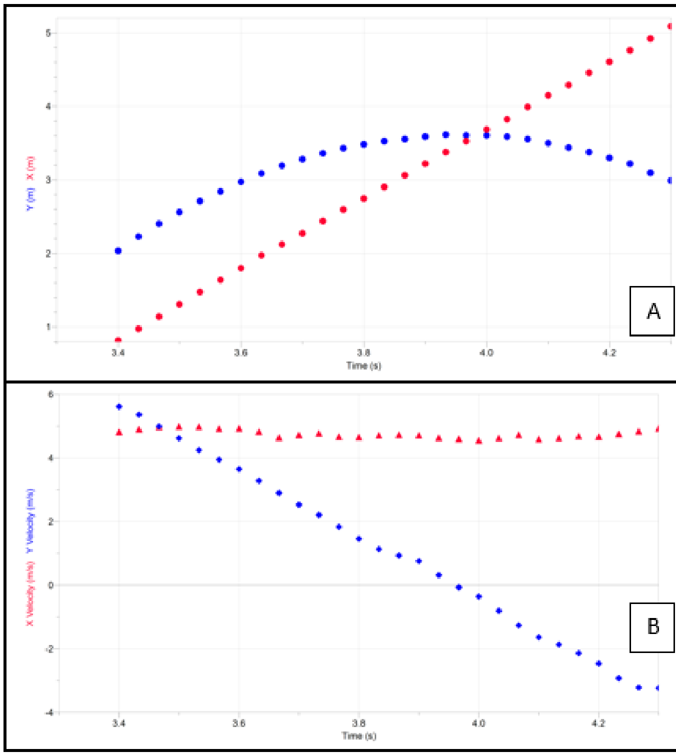


Figure 4. View within Logger Pro of a projectile motion example.



	VideoAnalysis				
	Time (s)	X (m)	Y (m)	X Velocity (m/s)	Y Velocity (m/s)
1	3.400	0.8158	2.035	4.810	5.614
2	3.433	0.9737	2.228	4.894	5.362
3	3.467	1.140	2.404	4.969	4.996
4	3.500	1.307	2.561	4.985	4.620
5	3.533	1.474	2.711	4.978	4.247
6	3.567	1.640	2.842	4.920	3.947
7	3.600	1.798	2.974	4.927	3.648
8	3.633	1.974	3.088	4.817	3.282
9	3.667	2.123	3.193	4.635	2.902
10	3.700	2.272	3.281	4.715	2.529
11	3.733	2.439	3.360	4.766	2.208
12	3.767	2.596	3.430	4.664	1.835
13	3.800	2.746	3.482	4.649	1.462
14	3.833	2.904	3.526	4.708	1.133
15	3.867	3.061	3.553	4.722	0.936
16	3.900	3.219	3.588	4.708	0.760
17	3.933	3.377	3.614	4.627	0.314
18	3.967	3.526	3.605	4.591	-0.066
19	4.000	3.684	3.605	4.547	-0.358
20	4.033	3.825	3.588	4.620	-0.804
21	4.067	3.991	3.553	4.722	-1.265
22	4.100	4.149	3.500	4.583	-1.637
23	4.133	4.289	3.439	4.620	-1.864
24	4.167	4.456	3.377	4.678	-2.135
25	4.200	4.605	3.298	4.664	-2.463
26	4.233	4.763	3.219	4.746	-2.925
27	4.267	4.921	3.096	4.832	-3.216
28	4.300	5.088	2.991	4.927	-3.231

C

Figure 5. Projectile motion analysis in A) graphs of distance in x and y directions vs. time, B) graphs of speed in x and y directions vs. time and C) data

Points (3.7, 3.281) (3.933, 3.614)

A

$$m = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(3.614 - 3.281)}{(3.933 - 3.700)} = \frac{.333}{.233} = 1.43$$

$$Y - y_1 = m(X - x_1) = Y - 3.614 = 1.43(X - 3.933)$$

$$Y - 3.614 = 1.43X - 5.624$$

$$+3.614 \qquad +3.614$$

$$Y = 1.43X - 2.01$$

B

Figure 6. Calculations for A) slope based on the points (3.7, 3.281) and (3.933, 3.614), and B) linear equation based on the points (3.7, 3.281) and (3.933, 3.614)

Numerous mathematical analyses are available at this point; examples include the following: 1) tangent of a line (to solve for slope at any location), 2) statistics such as mean, median, minimum and maximum, 3) integral and 4) linear or curve fit (creating equations such as

quadratic). Figure 6B shows the calculation of the linear equation based on the points (3.7, 3.281) and (3.933, 3.614)

3.4 Momentum, Force, and Work

Many physics-based concepts are difficult to conceptualize; examples include acceleration, force, work and momentum. Logger Pro contains the capability to make these calculations and more. Gravity is considered a constant that is ~9.81 m/s^2. Using the data from Figure 5C the accuracy of this gravitational constant from time 3.6 to 3.9 seconds is checked for accuracy. Figure 7 shows that LP calculates the acceleration for projectile motion to be 9.89 m/s^2. Figure 7B shows the work calculated in the x-direction and Figure 7C shows force and momentum calculated.

Time 3.6 to 3.9 seconds

A

$$\text{Acceleration} = \frac{(v_f - v_i)}{\Delta t} = \frac{.314 - 3.282}{3.933 - 3.633} = \frac{2.968}{.300} = 9.89 \text{ m/s}^2$$

Work = Force (distance)

B

$$F(\Delta d_x) = 5.9 \text{ N } (3.219 - 1.798 \text{ m})$$
$$5.9 \text{ N } (1.421 \text{ m}) \sim 8.4 \text{ J in "x" direction}$$

The basketball has a mass of .6 kg, what would the force and momentum be?

$$\text{Force} = \text{mass (acceleration)} = .60 \text{ kg } (9.89 \text{ m/s}^2) \sim 5.9 \text{ N}$$
$$\text{Momentum} = \text{mass (velocity)} = .60 \text{ kg } (8.6 \text{ m/s}) \sim 5.2 \text{ kg(m)/s}$$

C

Figure 7. Calculations from 3.6 to 3.9 seconds of A) acceleration, B) work in the x-direction and C) force and momentum.

4. Implementation

During the classroom examples, students are given the rules to recording videos as well as the steps to analyze motion within LP. In a flipped classroom, students would have access to materials,

such as videos and tutorials prior to class. There are three rules to follow when recording a video for analysis; the rules are as follows:

1. The camera needs to be set to record perpendicular to motion
2. The camera cannot be panned (moved during the recording)
3. A scale must be present within the shot

The steps for analyzing motion analysis within Logger Pro are as follows:

- Step 1: Insert>Movie; then select the video file
- Step 2: Click the three red dots in the bottom-right hand corner of the video
- Step 3: Play and stop the video right before motion begins
- Step 4: Click on the ruler icon and record a known length, such as a meter (the default distance)
- Step 5: Click on the single red dot and just click on what is moving as shown in Figures 2B and 4

5. Conclusions

Instead of some random numbers or random examples from some textbook, students have the ability to understand how fast they can (individually) run, how high or far they can jump, who can throw a football faster, who shoots a basketball at with a greater speed, acceleration, force, momentum or energy, and in turn giving students the capability to understand mathematical concepts of functions, Cartesian coordinates, dimensional analysis, graphical interpretation, slope, linear or quadratic functions. The methods described in this report outline a systematic approach to utilizing constructionism and a technological, pedagogical and integrated content knowledge.

Chapter 6: Mathematics and Earth Science-Based Knowledge and Learning Trends

Abstract

Test scores show that the Earth and Space Science domain continually places the lowest internationally, nationally, and across Texas. Earth science is consistently the lowest performing content area for every region within Texas. State exams show the percentage of students that reach an advanced level on mathematics scores in the highest populated local district are three times lower than the region and the state averages. This report discusses methods and outcomes of a two-year professional development program for mathematics and science teachers. Due to the program being conducted in one of the lowest performing and highest poverty regions in Texas, activities focused on technology relevant to learners' daily lives for this population. This report details successes and failures of integrated math and Earth Science activities of a professional development grant for teachers, the reasons behind targeting eighth grade teachers, and some reasons that could explain these disturbing trends.

1. Introduction

The Trends in International Mathematics and Science Study (TIMSS) is the longest-running assessment of mathematics and science in the world; this evaluation is used to measure student interest, engagement, confidence, and content knowledge every four years (TIMSS, 2016). The results from the 2011 and 2015 TIMSS assessments were very alarming for the United States (U.S.) because between the fourth and eighth grades, students in the U.S. lost interest, engagement, and confidence in their math and science abilities (Martin, Mullis, Foy, & Stanco, 2012; Martin,

Mullis, Foy, & Hooper, 2016; Mullis, Martin, &, and Arora, 2012; Mullis, Martin, Foy, & Hooper, 2016).

Although American mathematics and science scores have improved since 1995 (TIMSS, 2011), other countries pass established benchmarks at a rate of up to four and seven times the percentages of U.S. eighth grade students in science and in mathematics, respectively. The number of eighth grade U.S. students that liked learning mathematics or science, value science, or are engaged in math or science were all less than international averages in 2011 (Martin et al., 2012; Mullis et al., 2012). On a global scale, the 2015 TIMSS scores show U.S. students were below other countries in the percentages of students that like learning science or found teaching to be engaging in fourth and eighth grades (TIMSS, 2016).

Region 19 represents the westernmost portion of Texas, and there are many reasons why Earth and Space Science should be an exciting experience for students within this area. Some examples include dinosaur tracks, remnants of a Great Barrier Reef system, a field with over 100 volcanic cinder cones, and an active rift boundary. Despite the excellent opportunities to study local geologic features, Earth and Space Science is rarely taught in Texas high schools. Earth and Space Science had the lowest international average scores in fourth and eighth grade in 2015, and Earth and Space Science was the weakest performing content area in the U.S. in the fourth grade on the international assessments in 2011 (TIMSS, 2016). Earth and Space have been consistently one of the lowest tested reporting categories in Texas (*Texas Assessment*), but there is a typical pattern of mathematics and science test scores that are far below region and state averages in this area of Texas.

So the question arises, “what obstacles do students from this region of Texas face which prohibit science and mathematics content mastery?” Pre-assessments for our professional development grant indicated that Region 19 teachers lacked specific skills such as discipline integration, graphical interpretation, technology usage, and scientific logic. Many of the teachers selected to participate in the grant were inexperienced or lacked a background in mathematics and science content. Teachers were not prepared to use emerging technologies in practical and positive ways; they struggled to make connections to the local population or were lacking knowledge of effective teaching strategies that they could employ in their classrooms. Teachers were mostly unable to make connections to the local community due to cultural and language differences. Observed deficiencies in student performance and the evidence of a lack of knowledge in our local teachers indicated a strong need to improve local teaching through professional development programs.

To address these deficiencies, the authors of this report received a federally funded grant from the Higher Education Coordinating Board. The goal was to conduct a professional development program with eighth grade mathematics and science teachers from public and private schools, to teach standards-based content and to help teachers integrate mathematics, science, and technology into their classrooms. Forty-three teachers from Region 19 participated in the program. Collectively, the 43 teachers taught over 3,700 students daily.

During professional development, participants enhanced their technological, pedagogical, and content knowledge (TPACK) in mathematics and science and acquired knowledge of student misconceptions and how to address these misunderstandings. Niess (2005) and Mishra and Kohler (2006) proposed the TPACK framework. Because local student science performance was the lowest in the state at the eighth grade-level, TPACK framework was essential. This report

discusses potential reasons for student deficiencies, obstacles of Earth Science from a state-mandated curriculum and how new legislation limits content knowledge, perspective, and coursework. Successes and failures of the professional development workshops along with the targeting of eighth grade students and notable trends in academic student motivation and necessary life-long educational decisions are also analyzed.

2. Statement of the Problem

2.1 U.S. Learning Trends between Grade 4 and 8 Related to Math and Science

Unfortunately, TIMMS scores have shown a decline in interest, engagement, and confidence between fourth and eighth grade nationwide. Figures 1 and 2 display these disturbing mathematics and science trends for American students. The percentage of U.S. students that admitted to not liking science almost doubled between fourth and eighth grade (Martin et al., 2012). In 2015, TIMSS scores showed between the fourth and eighth grade the number of American science students that do not like science and are not confident in science almost doubled, whereas the number of students that are less than engaged in science nearly tripled as shown in Figure 2 (Martin et al. 2016). International assessments can describe how the nation is doing, but national data is needed to compare Texas to other states.

The National Assessment of Educational Progress (NAEP) is an assessment used to track U.S. achievement over time; the National Center for Educational Statistics (NCES) administers the NAEP and gives the U.S. Congress an annual report on June first entitled, The Condition of Education. NCES scores in 2015 showed that Texas eighth graders placed 22nd out of 50 states in both mathematics and science, and that fourth and eighth graders in Texas scored just above national averages in math and science (NCES, 2017). The NAEP does not provide categorical

information, so only TIMSS scores show which areas of science American students are scoring the lowest.

The 2011 TIMSS scores show that Earth and Space was the lowest tested reporting category for U.S. students at the fourth grade level (TIMSS, 2016). Lim and Sireci (2017) linked the TIMSS and the NAEP to track U.S. achievement over time and to compare scores of U.S. students on these two examinations. Using 2003, 2007, and 2011 TIMSS and NAEP data, Lim and Sireci (2017) concluded that U.S. student's mathematics scores improved more than average at Basic and Proficient levels, but lower than average at the Advanced level. Nationally, student surveys in 2011 showed that students from fourth to eighth grade that liked mathematics decreased from 45% to 19%, confidence in math declined 16%, and engagement in math dropped from 46% to 19%, meaning for every 2.4 students mathematically engaged in fourth grade, only one will still be engaged by the eighth grade (Martin et al., 2012; Mullis et al., 2012).

Between fourth and eighth grade, the Texas education system does not support interest, excitement, motivation or engagement in mathematics and science when compared to the relative national or international systems. The most recent TIMSS scores from 2015 showed the same alarming trend of students both internationally and nationally of considerable loss of interest, engagement, and confidence in mathematics and science from grades 4 and 8 (Martin et al., 2016; Mullis et al., 2016). One good comparison from the U.S. to the other nations in the study is that internationally by eighth grade, 40% of students had lost confidence in science abilities, whereas in the U.S. only 30% of eighth grade students had lost confidence. On the other hand, almost half of eighth grade students in the U.S. disliked math, which is much higher than the international average. The same trend of a dramatic drop off between fourth and eighth grade is displayed from

the last TIMSS assessment, showing that it is a perpetual trend at both national and international levels.

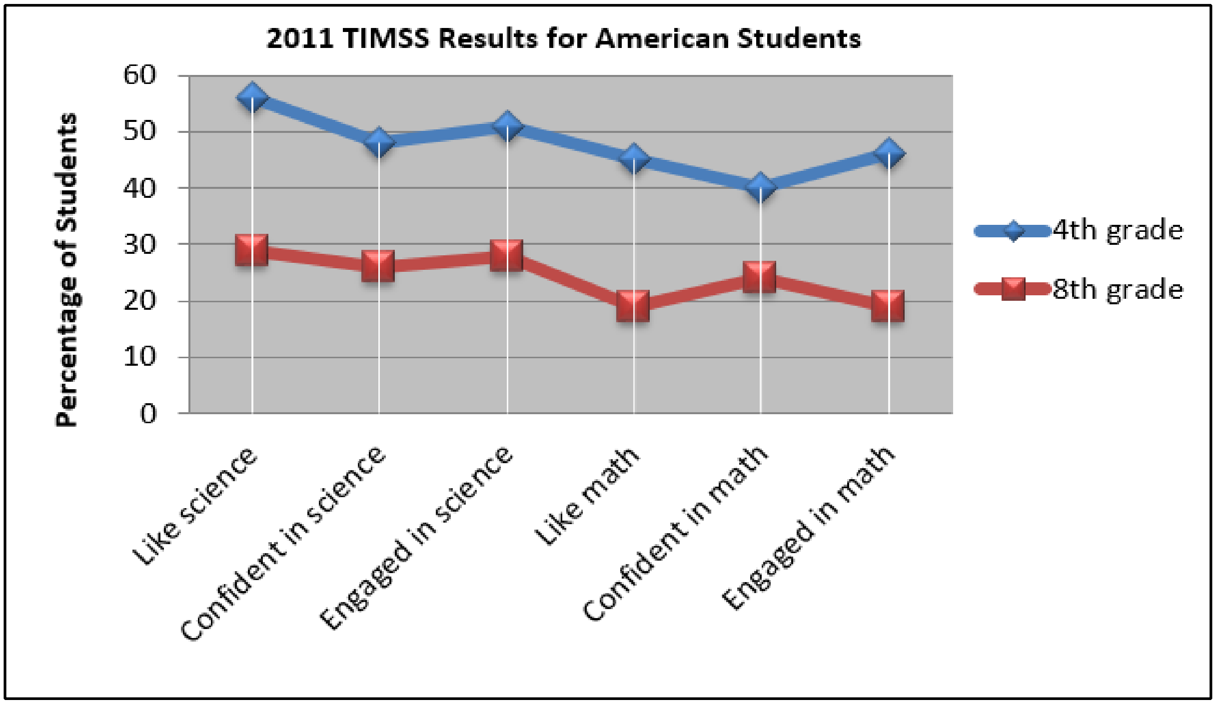


Figure 1. TIMSS results U.S. student attitudes about mathematics and science (based on Martin et al., 2012, Mullis et al., 2012).

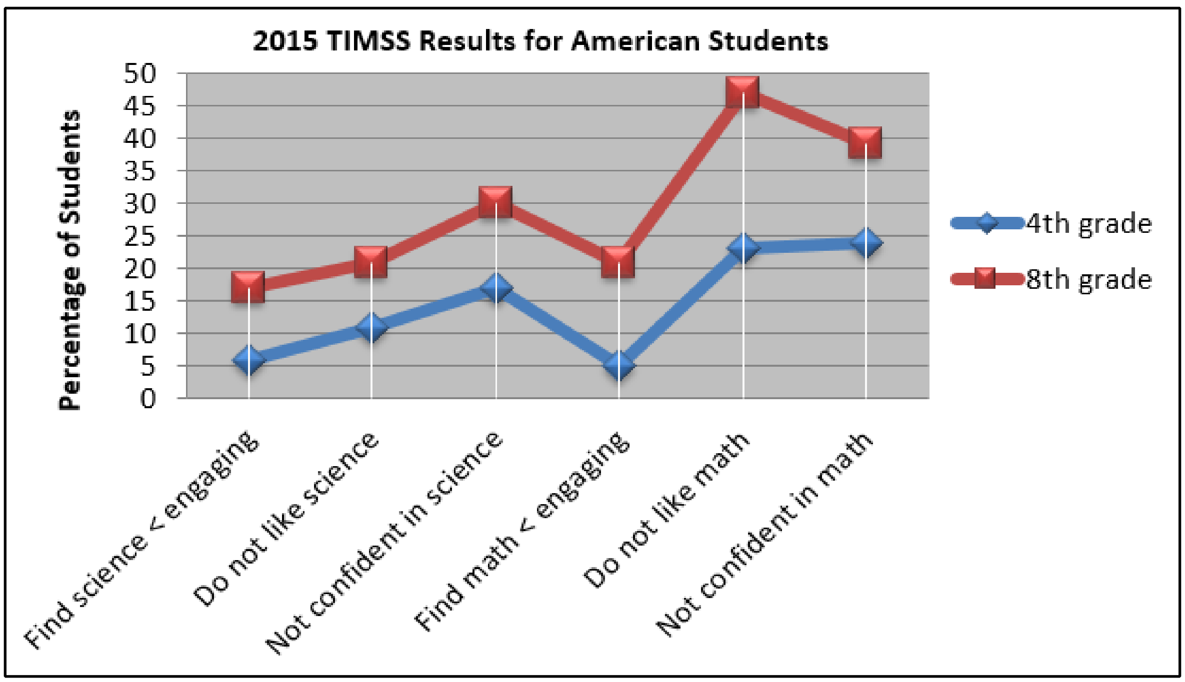


Figure 2. 2015 TIMSS international results displays the same trends as 2011 in student attitudes about mathematics and science between 4th and 8th grade (based on Martin et al., 2016, Mullis et al., 2016).

Connell, Halpem-Felsher, Clifford, Crichlow, & Usinger (1995) examined behavioral and psychological factors and school and contextual variables and concluded that the most predictive factor of students dropping out is lack of engagement. Even after controlling for effects of academic achievement and student background, student engagement shows to be a predictive factor of students dropping out (Connell et al., 1995). Basu and Barton (2007) and Rahm (2007) reported that underrepresented and immigrant students are frequently at higher risk of losing interest due to cultural and linguistic disconnects between school and life outside of school. Before students can value Earth Science or find engagement, the teachers need to establish efficacy and quality instruction first. Engagement is both a predictor of teaching quality, better grades, and achievement (Leon et al., 2017). A study from Betzner and Marek (2014) showed that secondary students had more positive perceptions of Earth Science and its educational value than teachers. SALG surveys measured content knowledge and efficacy of teachers before and after 124 hours of professional development.

2.2 State, Regional and District Trends between Grades 5 and 8

Texas has 20 educational regions. Region 19, where this study occurred, is unusually low performing in eighth grade mathematics and science test scores. According to *Pearson Access*, state-mandated exam scores from April 2013 indicated eighth grade mathematics students from the most massive local school district answered only about half of the mathematics questions correctly, and students from the region scored lower on every section of the mathematics and science exams than state averages. Local eighth graders were the third worst in the state in mathematics and the lowest at critically thinking with only 7 out of 100 eighth grade students reaching content mastery in science. Within a local classroom 82% of students were identified as

Economically Disadvantaged, 36% as *Limited in English Proficiency* and, 85% as an *Under-represented minority* based upon grant applications provided by the teachers.

The April 2013 eighth grade state-mandated exam showed that the Earth and Space reporting category was the lowest in 18 out of 20 areas in the state. The 2015 Texas state exam showed little difference because fifth and eighth grade science exam results from April 2015 showed that students scored lower in Earth and Space than any other reporting category. The April 2016 exam showed fifth grade students scored the lowest on Earth and Space than any other reporting category (*Texas Assessment*). On the April 2016 exam, fifth grade students scored lower in Earth and Space Science in 19 out of the 20 regions (*Texas Assessment*). Some of the science reporting categories for the most populated local school district on the 2015 state exam were up to 20% lower than state, and region averages and eighth grade students scored approximately 15% lower than the mean reporting categories in Texas and the region (*Texas Assessment*). Collectively, this means Earth and Space is the worst category of content mastery in Texas. Figures 3 and 4 show the science trends of Texas, the Region 19 and the largest local school district. The lowest performing science category for both local school districts and the entire state is Earth and Space.

According to *Texas Assessment*, eighth grade mathematics students in the largest local school district scored lower in every single reporting category than the state and the Region 19 in 2015, 2016, and 2017; the mean for the reporting categories was 5.5% lower than the state and 6.5% lower than the region during this span. On the spring 2017 assessment, eighth grade mathematics students in the largest local school district had only 4 out of every 100 students reach Advanced on the exam; this was 300% lower than the state and region averages, and 1 out of 3 students did not meet expectations, again much less than the state and region averages (*Texas*

Assessment). On the March 2015 Texas state exam, eighth grade mathematics Texas students only answered 51% of the questions correctly on average in the reporting category of Geometry and Measurement, and only 6% of students reached an advanced status in the entire state (*Texas Assessment*). The spring 2017 Texas state assessment for eighth grade mathematics showed that out of the 20 regions each with four reporting categories, only one had a passing score, which was 70%, the other 79 reporting categories were all below 70% and from the spring of 2016, all 80 reporting categories were failing (*Texas Assessment*), meaning on average not a single region in Texas had a passing average in any category. The combination of the spring 2016 and 2017 state exams had one passing reporting category and 159 failing. Fifth grade mathematics students were reasonably close to state and regional averages in 2015, 2016 and 2017, but the trend of a dramatic drop-off before eighth grade that is evident internationally, nationally, and in the local school district. Figures 5 and 6 show the mathematics trends from state to district.

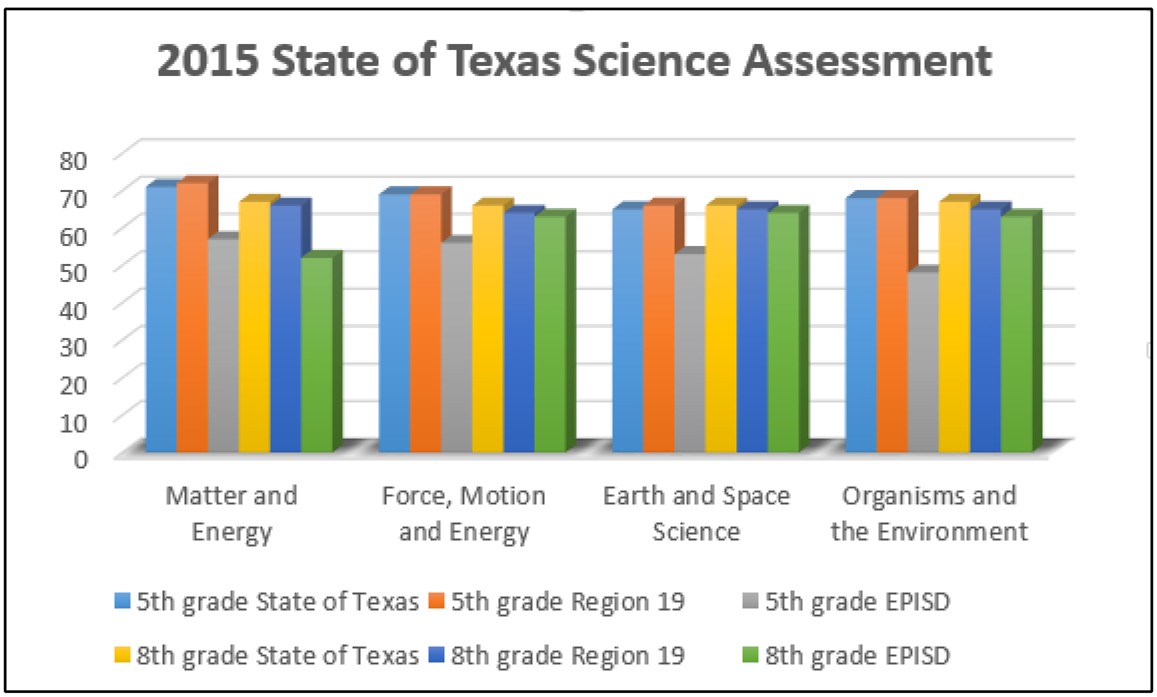


Figure 3. 2015 Texas Assessment science trends from state, region and local school district.

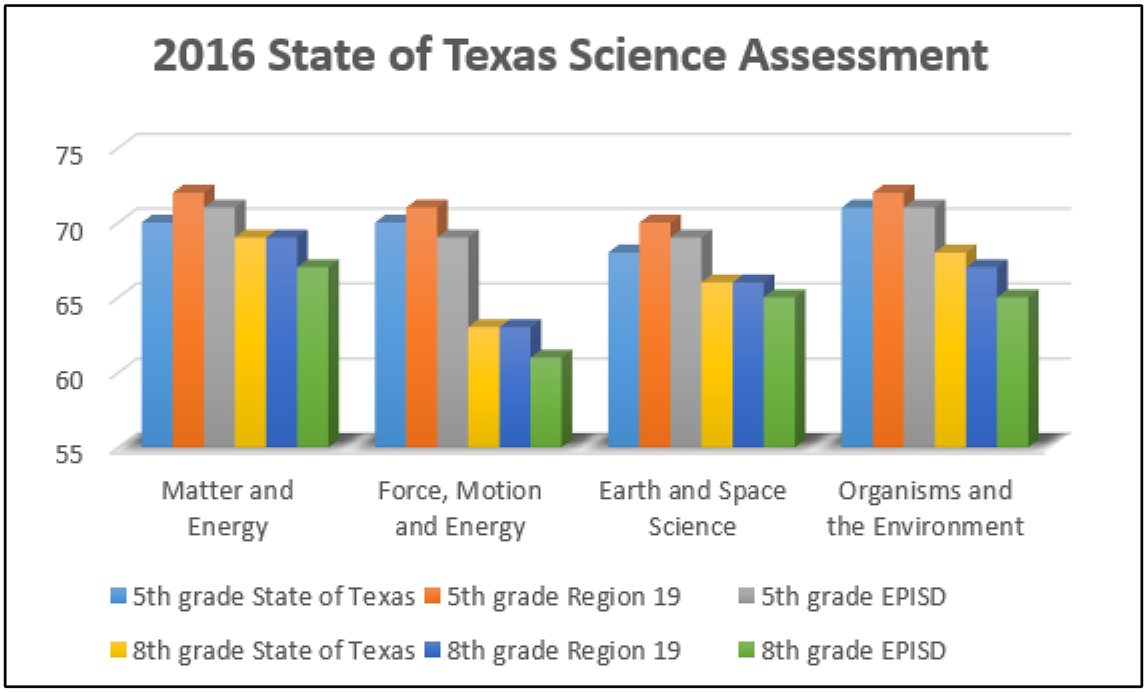


Figure 4. 2016 Texas Assessment science trends from state, region and local school district.

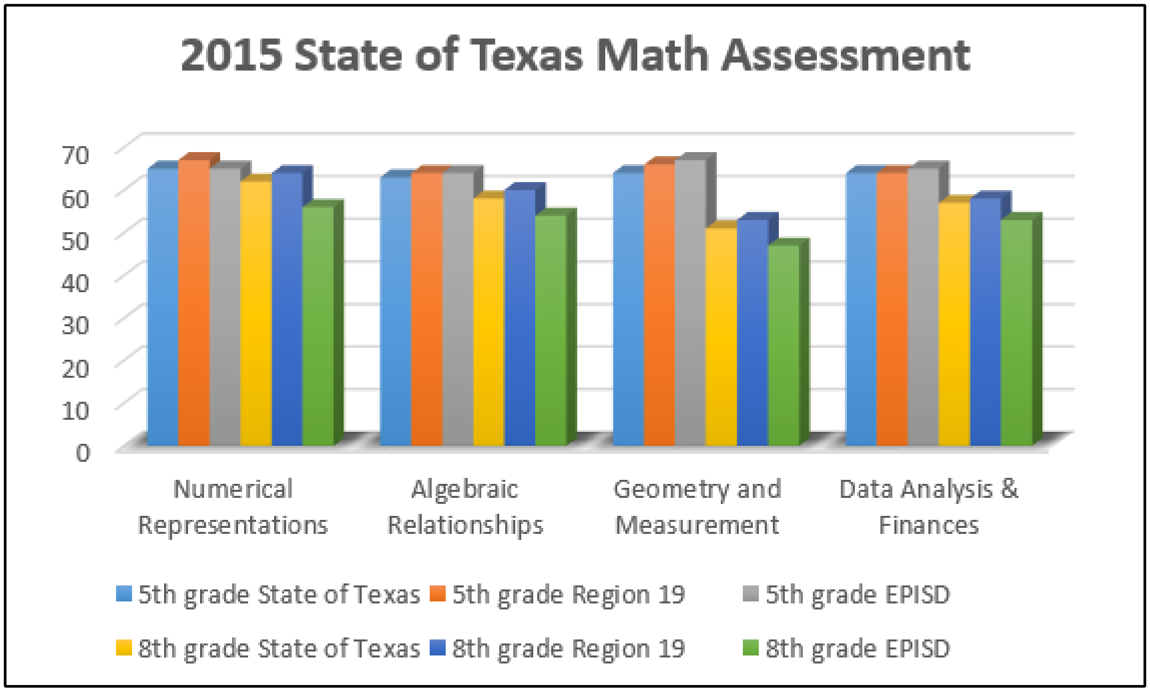


Figure 5. 2015 Texas Assessment mathematics trends from state, region and local school district.

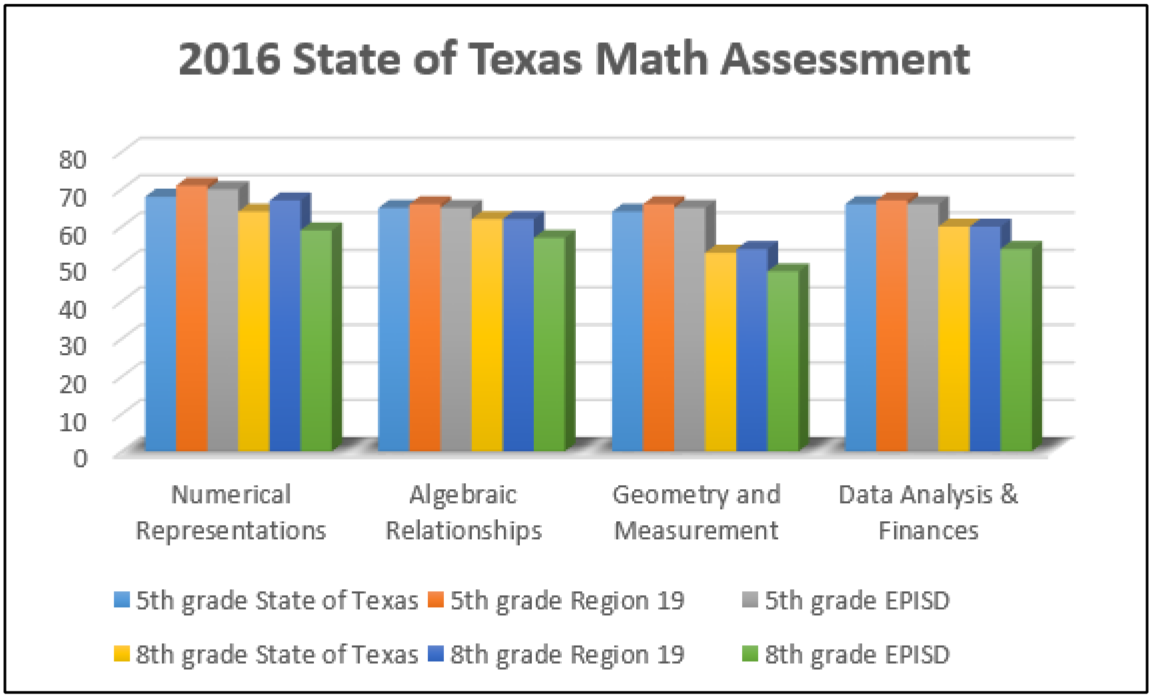


Figure 6. 2016 Texas Assessment mathematics trends from state, region and local school district.

2.3 Effects of Changes to State Curriculum

Trends are dissatisfactory for Earth and Space Sciences as regionally, nationally and internationally this category is continually and consistently the lowest. TIMSS scores show that students' confidence and interest have devastating drops across the board in mathematics and science between the fourth and eighth grade, both nationally and internationally (TIMSS, 2016). Content at the eighth grade level is focused on Earth and Space, meaning lower scores on grade level content are a further indication interest has taken a sharp decline between fourth and eighth grade. By the time a U.S. student is in eighth grade, less than one-third will like science, and less than one-fifth will like mathematics; this is when Earth Sciences are introduced based on state-mandated content and tested standards. Individual school districts decide how they are going to teach standards.

2.3.1 Reduced Testing

Due to a recent state U.S. House Bill, the requirements for graduation have changed to include a reduction in both the number of courses and the number of standardized exams needed for high school graduation. This cut went into effect in the 2013-2014 school year. The number of mathematics and science exams required to graduate high school went from three to one; this caused a change in the science course taught. Fourth-year courses or what are considered "capstone courses" will no longer be required to graduate. This decision eliminated the necessity for all high school students to complete four years of science, and a three-year plan has been established for all current high school students to meet the minimum requirements. These are Biology in the first year, Integrated Physics and Chemistry (IPC) or an advanced science during the second year, and an advanced science the third year, such as Chemistry or Physics. IPC is a minimal content version of Physics and Chemistry that does not truly prepare students for college

study in either discipline. IPC is a one year course that does not cover the equivalent of one year of physics and one year of chemistry. The rigor nor the content are comparable. Most local high schools have students take Biology, Chemistry, and then Physics for the prerequisites for high school science. Before this change, districts began establishing dual credit or Advanced Placement courses which allowed high school students to earn college-level credits concurrently with high school credits and encouraged college and career readiness. This resulted in increased learning expectations for teachers by supporting teachers to acquire graduate degrees in content areas specific to those being taught or to courses that align with local community colleges. With a recent change of 15 mandated state exams reduced to five, and with a growing likelihood it will soon be four exams, it seems the pattern is to reduce the number of tests to save money. Examination costs, time administering 15 exams, or the effect on graduation rates when students did not pass are the required examinations could have also factored into the dramatic change of mandated exams.

With the sudden decrease in science requirements, a higher percentage of students will elect to follow the three-year science program as opposed to pursuing further science courses; this will dictated the courses the student select in the eighth grade. A recent U.S. House Bill also requires by law for students to choose an educational career path at the end of the eighth grade year (*Texas Education Agency*). Students decide at eighth grade which classes they will take in high school, but if less than one-third of students like mathematics or science nationally by eighth grade, then non-required coursework in either subject is unlikely added to the minimum for most students. New state legislation will not stop schools from offering the first three years of science due to being the traditional courses offered (Biology, Chemistry, and Physics). One of the co-creators of Earth and Space curriculum for the largest local school district within Region 19 is D. Comeau. She said, "Changes to state legislation are eliminating many local fourth-year sciences

from many schools, such as Environmental Science, dual credit Geology and Earth and Space Science" (personal communication, June 16, 2014). Mrs. Comeau also mentioned that certain local schools and districts are already preparing for a decline in enrollment in mathematics and science by reducing course offerings, eliminating teacher positions, and changing teacher assignments (personal communication, June 16, 2014). Students only see most of the content listed within Earth Sciences in middle school, and the only chance to see it again would be during the senior year as an elective. Due to the decision to reduce the required science credits at the state level, most students will not be exposed to geology or Earth and Space Science again for the duration of their academic career in public schools after leaving middle school.

3. Obstacles for Academic Success

3.1 Negative Perception of Mathematics

TIMSS scores show that by eighth grade almost half of American students dislike mathematics (Mullis et al., 2016). State mandated tests are stressful and cause anxiety, but stress is only part of the resentment toward math. With mathematics, there is no room for error, so there is no way to say an answer is "close." Some students are anxious that they will provide an incorrect answer and this leads to a resistance to answering aloud or a lack of engagement to protect self-esteem. Several studies have tried to determine the causes of math anxiety. Wang, Hart, Kovas, Lukowski, Soden, Thompson, and Petrill (2014) investigated genetic and environmental factors contributing to anxiety during mathematical tasks. Genetic factors accounted for approximately 40% of mathematical anxiety. The genetic risk factors involved with math anxiety can make learning math more difficult, especially in those who have had bad experiences with math already (Wang et al., 2014). Chipman, Krantz, and Silver (1992) report math anxiety has a negatively association with scientific career interest. Everingham, Gyuris, and Connolly (2017) linked the

easing of anxiety and enhanced confidence with higher satisfaction, retention, and achievement. Many avoid or dislike math because of the teachers they had when they were in school, and in general, people tend to avoid what they do not understand. A common local saying is, "I just don't get math." What about disliking math due to traditional biases? One participant in our group said, "I'm not doing physics because I'm a female." How can we inspire teachers to motivate students when teachers themselves lack confidence and motivation? With such a strong resentment of math, motivation was the largest obstacle to overcome as science students do not have solid foundations in mathematics. This is an issue due to the interdependence of mathematics and science.

3.2 Characteristics of Student Aspects and Critical Thinking

One reason for low student achievement and interest could be that teachers are not considering what has traditionally been called student aspects. TPACK is a theoretical framework wherein teachers combine technological, pedagogical, and content knowledge. The beginning of the TPACK framework focused on knowing *student aspects* and critically thinking Shulman (1987). Shulman (1987) stated teacher knowledge needs to consist of learners and learner characteristics of community and culture. Grossman (1988) noted educators should know learners, student backgrounds, developments and misconceptions and Cochran, DeRuiter, and King (1993) later revised Shulman's (1986) educational context into an environmental context, illustrating the importance of outside factors. Some would suggest knowledge of learners is missing in the TPACK framework. Chigeza and Jackson (2012) mentioned a 'noticeable absence' of teacher knowledge related to individual learners and suggested language and culture must be clear and concise in the TPACK framework. Culture influences how people interpret the world, so different cultures have unique means of communicating and representing knowledge (Chigeza & Jackson,

2012). Jupit, Minoi, Arnab, and Wee (2012) proposed a culturally-based content as a Cu-TPACK or cultural TPACK. Cross-cultural awareness encourages understanding and respect of the culture (Jupit et al., 2012). While some were focusing on student characteristics, others have focused on critical thinking within the TPACK framework. Skemp (1976) and Kinach (2002) helped the framework with definitions of instrumental and relational learners and content knowledge. With all this work to improve the structure, new TPACK branches could be considered, such as *student aspects,* critical thinking, and content integration.

3.3 Teacher Inexperience

Teachers should know the *student aspects* of students, but students should also be aware of the prior knowledge of teachers. Shulman (1986; 1987) stated that learning to teach is a critical stage, and related this to Piaget's studies of knowledge and childhood development. Piaget (1952) suggested cognitive development progresses through a series of four stages. Grossman (1988) followed Shulman's work exclusively with beginning teachers. Inexperienced teachers have problems utilizing student characteristics as a way to reach and impact students, so students should be cognizant of the relative experience of their teachers. Fourth and eighth grade students with more experienced and confident teachers had higher achievement in both mathematics and science internationally (Martin et al., 2012; Mullis et al., 2012). On average, the percentage of international teachers with a Bachelor's degree was 79% for fourth grade math and 87% in eighth grade math; for science, 80% of fourth grade teachers and 90% of eighth grade teachers (Martin et al., 2012; Mullis et al., 2012). All participants in our grant had attained a Bachelor's degree, but in-service teachers were well below international averages for years of teaching experience. Internationally, eighth grade teachers with 10 or more years of experienced totaled 64% of math teachers and 62% of science teachers (Martin et al., 2012; Mullis et al., 2012).

In the 2012-2013 year of the grant, less than 13% of teachers had ten years of experience, and in 2012-2013 it was less than 12%. In the 2012-2013 year of the grant, the average years of teaching experience for participants was 6.0 years; 22% of the teachers had two or fewer years of teaching experience, and Alternative Certification certified 52% of the teachers. The 2013-2014 grant year had the average years of teaching experience decreased to 5.3 years, but those with less than two years of teaching experience went up to more than one-third. Alternative Certification certified 53% of the teachers in the program in 2013-2014. Figure 7 shows some of the selection criteria of the underqualified teachers.

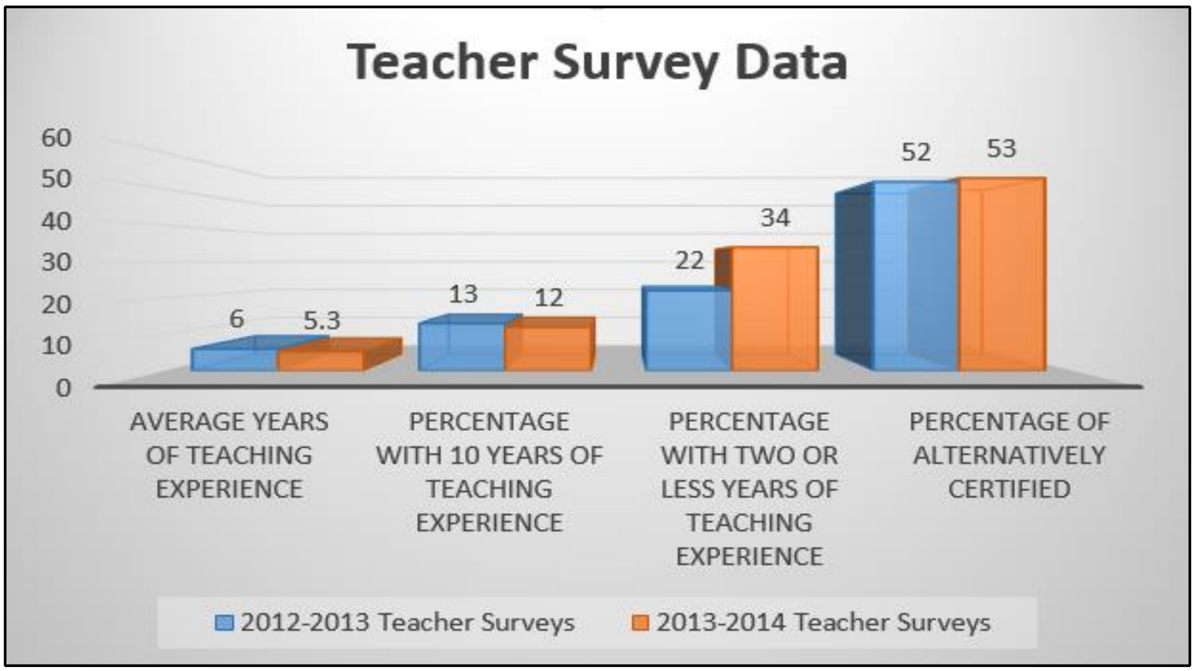


Figure 7. Examples of local teachers being underqualified based on survey data

3.4 Science Takes a Back Seat

There is a general understanding that mathematics and reading are the only state-mandated examinations required to pass fifth and eighth grade to be promoted to middle and high school respectively. Pamphlets from the largest school district in Region 19 were sent home to parents of students; these brochures state the only requirements for promotion to middle or high school

are to pass the mathematics and reading exams. The eighth grade Student Success Initiative is prominently displayed on the school district's website (EPISD). The Texas Education Agency (TEA), the agency responsible for the education of the state, created an initiative called Student Success Initiative and on the TEA website states that "students receive instruction and support to be academically successful in reading and mathematics" (SSI, 2017).

Students that fail state examinations in mathematics or reading are placed into additional classes the following school year, but not if said students are failing core subjects such as science, social studies or any other courses. These classes are called "intervention classes," and students can also be placed into them if passing grades on mathematics and reading class averages are not attained in the prior year. Students are not enrolling in classes because they "want to" but instead because they "have to," and thus, eliminating desired electives. This is probably a reason for such decline from fourth to eighth grade because if there are any signs of a student falling behind the classes they would prefer to take are replaced with reading and mathematics, in a sense ostracizing students.

Beyond K to 12, the vast majority of those with a path to become 8 to 12 grade science educators chose Biology concentrations. Approximately 3 percent of high school teachers in science, math, and computer science attained their highest degree in geoscience (Gonzales, 2011). A study by Betzner and Marek (2014) showed secondary teachers do not think classes in Earth and Space Science are as crucial as Physics, Chemistry, and Biology.

The "Teaching Science in Secondary Schools" class from the local university had 73% of the preservice teachers list Biology as their major in spring 2013, 78% of preservice teachers had Biology as their major/concentration in fall 2013 and 78% in spring 2014. With almost four out of five local preservice teachers selecting a Biology concentration, the logic appears to be that

Biology is the course that requires the least preparation. The closest state university has lower requirements in mathematics for a degree in Biology than other fields of science. Students could be consistently behind in Earth and Space Science in every region of the state, mainly due to a lack of teacher knowledge of said subject. The percentage of preservice teachers in these classes that declared geology as their majors were 0% in spring 2013, 6% in fall 2013 and 11% in spring 2014. Freshman high school science is purposely designed to have few prerequisites because the thought is that at this time students will not have completed sufficient mathematics for the other sciences. Students will be studying Algebra I when they take Biology. There appears to be an assumption on the part of the Texas State Board of Education that students will not learn enough mathematics during their high school career to pass a regular Physics or Earth Science course that might prepare them for college-level science, engineering, or environmental studies that lead to high demand employment. Figure 8 the frequency of readiness and supporting standards on Texas state examinations from 2012-2016 in Life Sciences compared to Earth and Space Science (Lead4ward, 2017). On average, both types of state standards are tested more frequently in topics related to Life Science than Earth Science (Lead4ward, 2017). Maybe if teachers are consciously aware that Life Science topics will, in fact, be tested more frequently, they will, in turn, concentrate on those topics more during a school year.

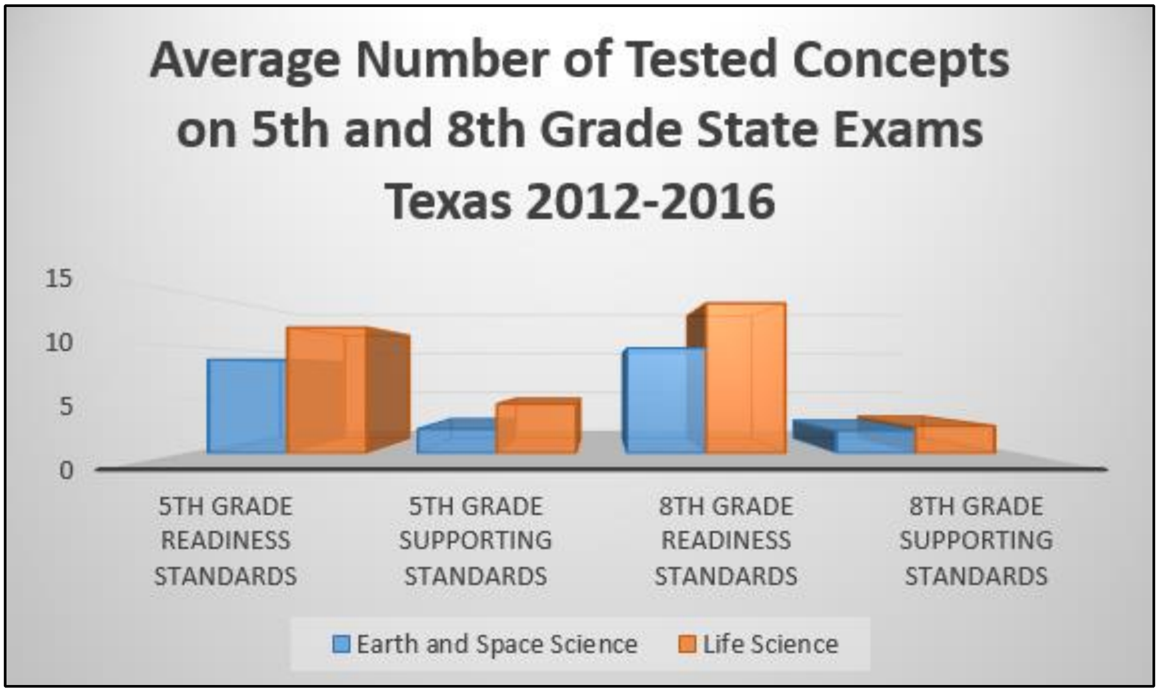


Figure 8. Shows that Life Science standards are tested more frequently than Earth Science standards based on Lead4ward data.

4. Methods

Recruitment involved teachers who were not adequately prepared to teach mathematics or science. Examples of teachers not being prepared include: teachers that had received Alternative Certification, had insufficient college coursework in their teaching assignment, or had failed to pass the state-licensing exam in the grant-related teaching assignment. Many participants selected for the grant did not possess a degree in science or mathematics. Participants were recruited using recommendations from participants in earlier programs who encouraged their colleagues to apply to the program and recommendations to teachers from the training headquarters for teachers in this region of the state.

Weekly professional development meetings were conducted over a two year period (2012-2014) using a practitioners' approach, with 124 contact hours per. In addition to the mathematics and science content, the emphasis was placed on the use of student-centered classroom instruction

and technology to convey content effectively. Examples of technology used in the grant include *iBooks Author*, *iMovie*, various iPad applications, Apple TVs, *Google Earth* and diverse presentation and screencasting software. Teachers collaborated on how to motivate their students and to create lessons that provided transformative learning experiences. Four-day intervals of mathematics, science, technology, and classroom methods/practices formed the basic model used for professional development. Usually, one out of every four days was set aside for teachers to present their ideas based on the topics covered in former professional development opportunities. The technology was used to integrate mathematics and science content to during workshops, and The Students Assessment of Their Learning Gains (SALG) survey was used to measure efficacy and content knowledge (Seymour, Wiese, Hunter, & Daffinrud, 2000).

5. Participant Data

5.1 2012-2013 Participant Data

The 2012-2013 Teacher Quality (TQ) Grant worked with teachers from eight local middle schools. The majority of the participants were under-represented minorities, which was comparable to the city's average (United States Census Bureau). There was an unusually discrepant ratio of males to females of almost three-to-one and only 17% of the teachers were working for a charter school. Teachers had more than four-out-of-five of the 1,839 students were labeled *Economically Disadvantaged*, and more than one-out-of-three were labeled as *Limited in English Proficiency*. In working with the Teachers for the 2012-2013, it was clear both math and science teachers were lacking specific skills, such as integrating disciplines, graph interpretations, ability to incorporate technology, and relation to real-world contexts. Pre and post-test scores indicated minimal gains in Earth Science content knowledge.

5.2 2013-2014 Participant Data

The 2013-2014 participants were inexperienced and lacked solid foundations of content knowledge in the fields in which they teach. In the 2013-2014 year of the grant, none of the teachers had a degree in science or mathematics. Three of the teachers had a Bachelor's of Science: one in Graphic Design and two in Engineering, and the rest of the degrees possessed by the participants in the grant were Interdisciplinary Studies, Education, Communication, Psychology and/or Business Administration. Working with an increase from 17% to 41% of the teachers from charter schools has caused some significant changes to the grant. In 2013-2014 the grant worked with local area teachers from three local middle schools. Second, the percentage of females went from less than one-third to more than half with an 8:9 ratio. Finally, the grant went from 74% down to 52% Hispanic. The number of *Economically Disadvantaged* went from 82% down to 61%. Those *Limited in English Proficiency* remained a constant 36% (same as the previous year). Even with six fewer teachers in 2012-2013, the participants were directly affecting more students than the previous year: 1,865 students.

6. Discussion

At the beginning of this project, the goals were relatively simple; students in our region were starting college poorly prepared for mathematics and science coursework, and the grant provided an opportunity to address some of the reasons for the lack of preparation. Because Region 19 is one of the lowest performing and critically thinking in the state in mathematics and science, and because the TIMSS report indicated the eighth grade was a critical time for students to lose interest in science and mathematics, the program focused on eighth grade mathematics and science teachers. At this grade level, students choose an endorsement, or what courses they will take in high school and beyond. Many students in this region start "Early College" with college

coursework immediately after finishing the eighth grade, so if a professional development program targets only high school teachers, then Early College students would not benefit. Drastic reductions in state-mandated exam scores indicate a severe decrease in eighth grade content knowledge.

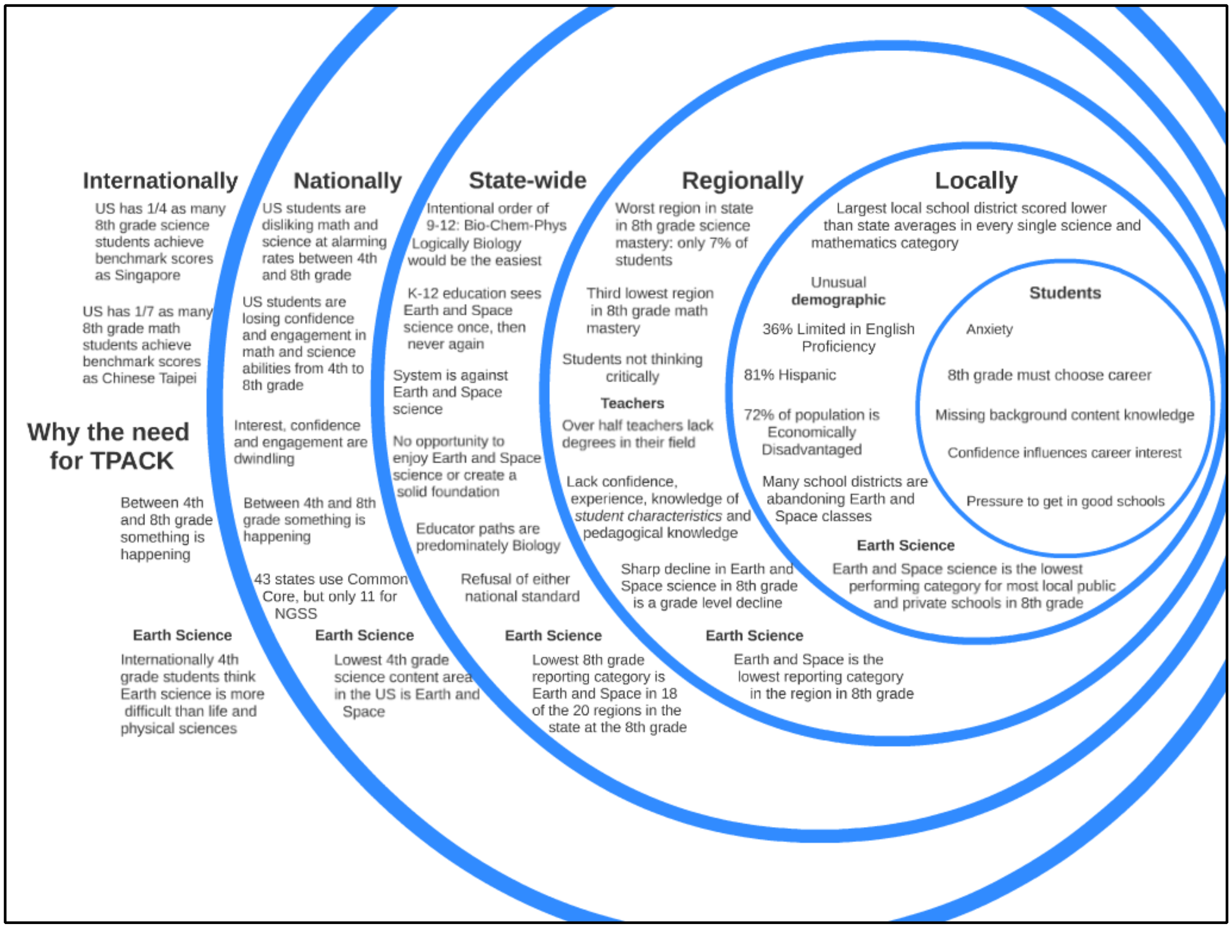


Figure 9. Summarizes the need for TPACK teacher training by strengthening mathematics and science teaching and learning; explicitly showing Earth or Earth and Space Science is lowest content area nationally; state-wide, regionally and locally.

The eighth grade content is mostly Earth and Space Science, which is an area where teachers do not have much content knowledge, so this would be a great time to learn how to teach these sciences (as shown in Figure 9). The TPACK approach of combining conceptual knowledge with pedagogy and technology was well suited to the skills and interests of the grant recipients. In particular, the project focused on multiple teachers in both mathematics and science from a few

schools to build collaboration between disciplines and encourage teachers to integrate mathematics and science in all of their classrooms. Based on observations and reflective journals, there did appear to be an increase in participant appreciation of using science and math together in the school. Teachers demonstrated both interest and skill in adding technology to their classes. Responses of the math teachers to science-dominant lessons were very positive.

6.1 Fostering Community

Recruiting participants from the same schools were particularly successful for this program. The program benefited from an earlier, 2009-2012 professional development program that addressed mathematics and science in grades 6 to 9, and the participants from the previous program were the ones who recommended many of the participants for the program described here. The earliest participants in the program brought in other teachers from their schools after the first meeting so that there were eight schools involved immediately for the 2012-2013 school year. In 2013-2014, the authors of this report decided to work with teachers from fewer schools to build larger professional learning communities within individual schools. The different school groups made collaborative programs and began to plan activities across disciplines early in the program. Some participants had difficulty with one or more aspects of the program, but their colleagues stepped in to create a support plan where they shared skills and helped each other achieve goals. Most of the *iBooks* were the work of one primary leader at each school; other participants gathered material and contributed to the finished product. Only one school appeared to have difficulty with the collaboration, and that group produced two separate *iBooks* which both involved integrating science and mathematics.

6.2 Technology

Part of the grant required giving participants an iPad and teaching them to use it in the classroom. Many apps were introduced during the program, but the most widely used appeared to be *iMovie* and the video camera built into the iPad. We introduced *iMovie* early in the program and encouraged participants to record lessons so teachers could see what the students were learning. This method worked very well for most groups, and the teachers rapidly became proficient in making movies and using them in their classes. The student videos were an even more significant success because it allowed the students in the classes to express what they had learned using modern technology. The fact that the teacher showed trust in them by allowing students to take charge of a lesson and develop material for learning was an essential part of building a student-centered classroom.

The idea to use *iBooks Author* in our program was fostered by the success of a group of teachers from our previous grant who are now writing math eBooks for their school district using *iBooks Author*. The participants from our earlier program had encouraged several of our current participants to join the program. Newer participants informed the authors of this chapter that former teachers were using *iBooks Author* to create the textbooks, so the decision was made to use the software in our program. Unfortunately, *iBooks Author* was not introduced until relatively late in the program because iPads required an Apple computer to create the books. For those reasons, teachers did not become as skilled with its use as initially wanted and *iBooks Author* would need to be introduced earlier future programs. Despite the late start, teachers were able to incorporate these classroom-based educational videos into authored ebooks.

7. Conclusions

SALG assessments evaluated participants at the beginning and the end of the 2013-2014 program. Average test scores increased in 32 of the 37 domain with improvements in Skills, Attitudes, Earth and Science Content Knowledge and growth in every domain within Understanding and Integrating Learning. Figure 10 shows the p-values of the six Understanding domains with a significant change:

- 1.1.2 Understanding of Science--including Earth Science, Environmental Science, Astronomy, weather, and the physical properties of materials
- 1.1.5 Understanding the use of technology such as iPads, videos, iBook authoring as a teaching aid
- 1.2 Understanding the relationships between those central concepts and my teaching
- 1.3 Understanding how ideas explored in this program relate to ideas I have encountered in other programs within this subject area
- 1.4 Understanding how ideas explored in this program connect to ideas I have encountered in outside of this subject area
- 1.5 Understanding how studying this subject helps people address real-world issues

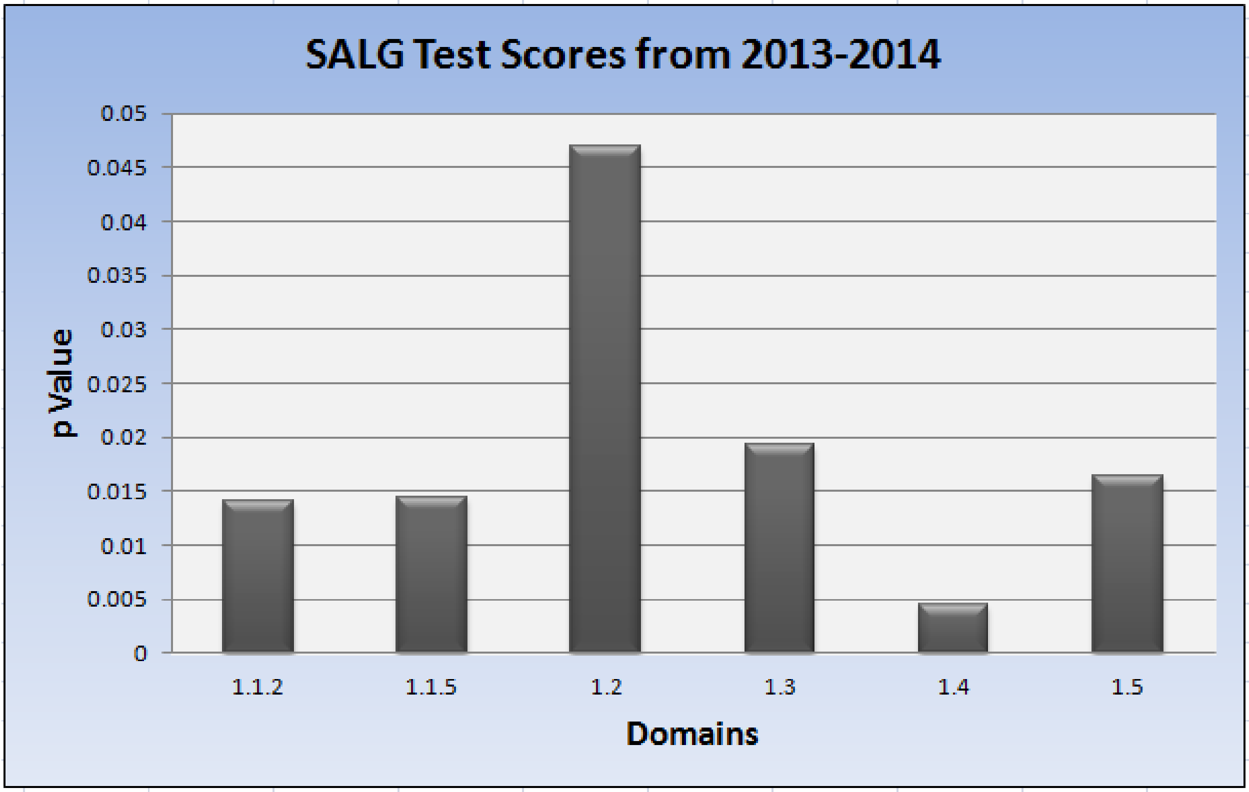


Figure 10. The Students Assessment of Their Learning Gains efficacy and content knowledge test scores in Earth Science for 2013-2014 participants showing a significant change in six different domains.

The primary motivation of the grant was the apparent disconnect between mathematics and science demonstrated by students entering the university. Subjects were taught as entirely separate topics throughout a student's education even at the college-level. Most of the math teachers did not use examples from science in their teaching because they had taken the introductory science classes required of all college majors and little else. Those introductory courses rarely require much mathematics. Similarly, most of the science teachers were not as knowledgeable about mathematics as might be expected because nearly all (~85%) of the science teachers in the region with a science degree had earned their science degree in Biology, which requires the least amount of math of any of the science disciplines. Many of the science and mathematics teachers had degrees in some entirely unrelated fields combined with Alternative Certification, which gave them only minimal conceptual knowledge of either math or science.

The professional development program targeted integration of both topics in math and science classrooms at the eighth grade level. In the past, teachers showed resistance with this approach. The opposition was more commonly from the mathematics teachers than from the science teachers. By the end of this program, there was clear evidence of a willingness to work across disciplines. Even though there was an increase in 86% of the SALG domains, there was only a significant change in 16%. The significant changes were in attitude and efficacy. After two years, teachers were much more confident to draw on the prior knowledge and use it in the classrooms than they had been coming into the program. Participants have adapted pedagogical knowledge into student-centered lessons and activities, technological expertise in new apps and software, videos and e-books, and integrated mathematics and Earth Science content knowledge. What made this program unique was not just the use of TPACK, but TPACK in conjunction with the integration of mathematics and science.

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Chapter 1

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Chapter 2

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Glossary

Alternative Certification: A program to take those with a Bachelor's degree and help them attain the qualifications to become a certified teacher.

Common Core: National standards for language arts and mathematics, which has currently been adopted by 43 states

Constructivism: Learning through building upon prior knowledge and experiences.

Constructionism: The theory that learning is the most effective while constructing material objects.

Dual credit: Courses that can be taken for both high school and college credit.

Early College: Students have the option to go to high school or challenge college placement exams and start college coursework immediately following eighth grade.

Endorsement: Before a student finishes the eighth grade they must chose an educational path, so high schools can know what classes need to be offered.

NGSS: Proposed national standards for science and social studies, which has currently only been adopted by 11 states.

PLC: A Professional Learning Community is when teachers meet to focus on curriculum, scores, students and horizontal alignment.

Appendix

A.1

Location/Rock Type	εHf(T)	Age in Ma
Aibo Granite[H]	-11.6 to -6.6	1075 ± 1.3
Sierritas Blancas Murietta granite[Ha]	-2.5 to +1.1	1084.3 ± 5.9
Rancho de Santa Margarita anorthosite[Ha]	-2.5 to +1.4	1089 ± 13
Pikes Peak Buffalo Park monzogranite[H]	-2.3 to +0.8	1091.4 ± 5.2
Sauk Sequence drill core (Colorado) [Ha]	-2 to +4	1096.4 ± 30.6*
Tava sandstone (central Colorado) [Ha]	-1.8 to 7.4	962 to 1289
Sierritas Blancas Murietta granite[Ha]	-1.6 to +3.0	1086.0 ± 8.7
Sierritas Blancas anorthosite[Ha]	-1.4 to +1.6	1095 ± 29
Pikes Peak syenogranite[H]	-1.1 to +2.2	1106.6 ± 5.3
Pikes Peak Batholith granite[G]	-0.8 ± 0.2	1066 ± 10
Escuadra Granite[H]	-0.5 to +3.2	1083.9 ± 8.6
Lake George ring complex monzogranite[G]	+0.4 ± 0.9	1078 ± 11
Wood Canyon Formation feldspanthic arenite[H]	+2.0 to +8.2	1100*
Little Hatchet Mountains granite[H]	+2.1 to +5.0	1077 ± 4
Pikes Peak West Creek quartz syenite[H]	+2.4 to +4.4	1089.7 ± 7.2
Franklin Mountains Mafic Dikes (LAM3)	+3.1 to +12.9	1123 ± 17.1
Franklin Mountains Mafic Dikes (LAM2)	+3.2 to +11.2	1124.1 ± 14.1
Franklin Mountains RBGS Stage 4[H]	+3.8 to +6.7	1124.5 ± 3.5
Franklin Mountains RBGS Stage 2[H]	+3.9 to +7.4	1116.9 ± 8.9
Franklin Mountains RBGS Stage 1[H]	+4.3 to +8.3	1122.6 ± 3.7
Pikes Peak quartz syenite[G]	+4.8 ± 0.2	1115 ± 12
Llano Uplift Grape Creek granite[H]	+4.8 to +8.5	1097.8 ± 8.9
Franklin Mountains RBGS Stage 2 (FR8)	+5.26 ± 0.69	1118.4 ± 5.4
Llano Uplift Lone Grove granite[H]	+5.5 to +7.0	1126.4 ± 8.8
Franklin Mountains RBGS Stage 2 (FR6)	+6.72 ± 0.62	1125 ± 3.4
Franklin Mountains RBGS Stage 1 (FR4)	+6.82 ± 0.63	1121.3 ± 2.9
Franklin Mountains RBGS Stage 2 (FR1)	+7.16 ± 0.95	1116.1 ± 8.7

Appendix A.1. Location, rock type, εHf (t) and age in Ma. Modified from Guitreau et al., 2016, (Ha)-Hantsche (2015), and (H)-Howard (2013). Asterisks indicate peak ages.

A.2 U-Pb Geochronological Analyses

Zircon crystals are extracted from samples by traditional methods of crushing and grinding, followed by separation with a Wilfley table, heavy liquids, and a Frantz magnetic separator. Samples are processed such that all zircons are retained in the final heavy mineral fraction. For igneous samples, high-quality grains are selected and mounted with standards, generally with four samples per mount. The mounts are sanded down to a depth of ~20 microns, polished, imaged, and cleaned prior to isotopic analysis.

U-Pb geochronology of zircons is conducted by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) at the Arizona LaserChron Center (Gehrels et al., 2006, 2008; Gehrels and Pecha, 2014). The analyses involve ablation of zircon with a Photon Machines

Analyte G2 excimer laser equipped with HelEx ablation cell using a spot diameter of 20 microns. The ablated material is carried in helium into the plasma source of an Element2 HR ICPMS, which sequences rapidly through U, Th, and Pb isotopes. Signal intensities are measured with an SEM that operates in pulse counting mode for signals less than 50K cps, in both pulse-counting and analog mode for signals between 50K and 5M cps, and in analog mode above 5M cps. The calibration between pulse-counting and analog signals is determined line-by-line for signals between 50K and 5M cps, and is applied to >5M cps signals. Four intensities are determined and averaged for each isotope, with dwell times of 0.0052 sec for 202, 0.0075 sec for 204, 0.0202 sec for 206, 0.0284 sec for 207, 0.0026 sec for 208, 0.0026 sec for 232, and 0.0104 sec for 238.

With the laser set an energy density of ~5 J/cm2, a repetition rate of 8 Hz, and an ablation time of 10 seconds, ablation pits are ~12 microns in depth. Sensitivity with these settings is approximately ~5,000 cps/ppm. Each analysis consists of 5 sec on peaks with the laser off (for backgrounds), 10 sec with the laser firing (for peak intensities), and a 20 second delay to purge the previous sample and save files. Prior to analysis, grains are imaged to provide a guide for locating analysis pits in optimal locations, and to assist in interpreting results. Images are made with a Hitachi 3400N SEM and a Gatan CL2 detector system (www.geoarizonasem.org). CL images were made for igneous mounts.

A.3 Hf Analytical Methods

Hf isotope analyses are conducted at the Arizona LaserChron Center with a Nu HR ICPMS connected to a New Wave UP193HE laser (2009-2010) or a Photon Machines Analyte G2 excimer laser (2011). Instrument settings are established first by analysis of 10 ppb solutions of JMC475 and a Spex Hf solution, and then by analysis of 10 ppb solutions containing Spex Hf, Yb, and Lu. The mixtures range in concentration of Yb and Lu, with ^{176}(Yb+Lu) up to 70% of the ^{176}Hf. When all solutions yield ^{176}Hf/^{177}Hf of ~0.28216, instrument settings are optimized for laser ablation analyses and seven different standard zircons (Mud Tank, 91500, Temora, R33, FC52, Plesovice, and Sri Lanka) are analyzed. These standards are included with unknowns on the same epoxy mounts. When precision and accuracy are acceptable, unknowns are analyzed using exactly the same acquisition parameters.

Laser ablation analyses were conducted with a laser beam diameter of 40 microns, with the ablation pits located on top of the U-Pb analysis pits. CL images ensure that the ablation pits do not overlap multiple age domains or inclusions. Each acquisition consists of one 40-second integration on backgrounds (on peaks with no laser firing) followed by 60 one-second integrations with the laser firing. Using a typical laser fluence of ~5 J/cm2 and pulse rate of 7 Hz, the ablation rate is ~0.8 microns per second. Each standard is analyzed once for every ~20 unknowns. Isotope fractionation is accounted for using the method of Woodhead et al. (2004): βHf is determined from the measured ^{179}Hf/^{177}Hf; βYb is determined from the measured ^{173}Yb/^{171}Yb (except for very low Yb signals); βLu is assumed to be the same as βYb; and an exponential formula is used for fractionation correction. Yb and Lu interferences are corrected by measurement of ^{176}Yb/^{171}Yb and ^{176}Lu/^{175}Lu (respectively), as advocated by Woodhead et al. (2004). Critical isotope ratios are ^{179}Hf/^{177}Hf =0.73250 (Patchett & Tatsumoto, 1980); ^{173}Yb/^{171}Yb = 1.132338 (Vervoort et al. 2004); ^{176}Yb/^{171}Yb =0.901691 (Vervoort et al., 2004; Amelin and Davis, 2005); ^{176}Lu/^{175}Lu = 0.02653 (Patchett, 1983). All corrections are done line-by-line. For very low Yb signals, βHf is used for fractionation of Yb isotopes. The corrected

$^{176}Hf/^{177}Hf$ values are filtered for outliers (2-sigma filter), and the average and standard error are calculated from the resulting ~58 integrations. There is no capability to use only a portion of the acquired data.
All solutions, standards, and unknowns analyzed during a session are reduced together. The cutoff for using βHf versus βYb is determined by monitoring the average offset of the standards from their known values, and the cutoff is set at the minimum offset. For most data sets, this is achieved at ~6 mv of ^{171}Yb. For sessions in which the standards yield $^{176}Hf/^{177}Hf$ values that are shifted consistently from the know values, a correction factor is applied to the $^{176}Hf/^{177}Hf$ of all standards and unknowns. This correction factor, which is not necessary for most sessions, averages 1 epsilon unit.

The $^{176}Hf/^{177}Hf$ at time of crystallization is calculated from measurement of present-day $^{176}Hf/^{177}Hf$ and $^{176}Lu/^{177}Hf$, using the decay constant of ^{176}Lu ($\lambda = 1.867e^{-11}$) from Scherer et al. (2001) and Söderlund et al. (2004). No capability is provided for calculating Hf Depleted Mantle model ages because the $^{176}Hf/^{177}Hf$ and $^{176}Lu/^{177}Hf$ of the source material(s) from which the zircon crystallized is not known.

Vita

With a B.S. in Geological Sciences, M.A. in Teaching Science, I, Anthony M. Alvarez have a wide-range of teaching experience. I have taught middle and high school as well as the Colleges of Science, Teacher Education and Geosciences at UTEP, teaching nine different courses. I co-created a new class at UTEP: SCI 1301.

I have collaborated on projects such as NMSU's Arid Land and Research for the Jornada Range under Dr. Craig Wilson from Texas A&M studying the corn earworm moth and two NASA team-research projects under Dr. Jose Hurtado. We studied fault scarps in the Portrillo Mountains, with small-format aerial photography which documented El Paso's earthquake history, and interpreted the Himalayan Mountains with remote sensing. I worked on the Teacher Quality Grant supported by The Higher Education Coordinating Board, and DIG Texas Blueprints, which designed curriculum for the entire state of Texas and funded by the NSF.

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