Pacific Petroleum Geology

NEWSLETTER

Pacific Section • American Association of Petroleum Geologists November & December 2018

Monterey and Sisquoc Formations, YPLS 2018, Racing Geologists, and Remembering A Member

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COVER PHOTO: View of the Upper Monterey Formation at San Miguelito Canyon, near Lompoc, California. Courtesy of Yannick Wirtz.

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Dear Pacific Section AAPG Members,

How many times have you heard of one company purchasing another's lease or land and then developing a new structural or stratigraphic model and revitalizing a declining field? How many plays were tried by different companies and abandoned, only to become a success when a new approach or idea was tried by someone else? I can think of a dozen examples in California of where a company's current principal production zone used to be considered only overburden to be drilled through to get to the real reservoir. These successes generally had to do with looking at data in a new way, developing, proposing, and testing a new idea that didn't fit in with the established understanding up to that point.

In the last newsletter, I discussed the nature of creativity and insight and some of the methods that have been employed to help scientists to innovate. In this letter, I would like to explore another aspect of creative discovery – and that's cultivating and encouraging diverse perspectives, both within oneself and within a team or organization.

Most of us have been exposed to the great geologist T.C. Chamberlain's "method of multiple working hypotheses", and may have even read his paper – as clear and pertinent today as it was when it was written almost 130 years ago. In it, he stressed the importance of not becoming attached to a single explanation prematurely, even though it may feel good to find a solution that seems to fit the data.

I'd guess that most of us try to follow this method in the early stages of exploring a new area or problem, but, in reality, we generally lock onto a preferred working model pretty quickly and then move forward. And, of course, you have to in the non-academic world or else nothing would get done.

However, that's also where the problem begins. Once a model is accepted, it begins to gain mass and rigidity. Money and reputations are spent based on "the model". New people come into the team and learn "the model". A group-think develops that may apply to a team, a field or a whole industry. And this works – for sure – because the people involved are smart, hard-working, well-trained professionals. But, once there is a working model, it isn't easy to open the door to new, innovative ideas that could lead to break-through discoveries. That usually takes a new perspective and a willingness by everyone to entertain different ideas. And this does not take place very easily in a mono-culture – where everyone went to the same schools, has the same training, accept the same ideas, and even accept the same wisdom as to what data are important or not. I can't count how many oil companies only go to recruit at their favorite schools, where their senior personnel and much of their staff were educated. This may assure that their new hires had a competent education, but it also nearly guarantees that everyone will come with the same ideas and the same approaches learned from the same professors.

If we want to be truly creative, then we need to embrace diversity – diversity in educational background, diversity in culture, diversity in expertise, diversity in personality, diversity in ideas and diversity in approaches. We need this in ourselves and in our teams. We are all doing so many different things these days, some that we never would have imagined in the past. Petroleum geoscientists are stratigraphers and structural geologists, petrophysicists, geophysicists and reservoir modelers for sure, but we are also business people, government liasons, groundwater hydrologists, geochemists, educators, outreach coordinators, pubic servants, environmental activists, and more.

Filling all of these roles takes a broad range of people with different talents, or it make take embracing different potentials within oneself at different times in a career. In any case, one model, one type of geoscientist does not fit all of the needs that exist. We need all of the strengths that we can muster, not just the ones that we are used to. You can't think "outside-of-the-box" when we all sit in the same carton.

Richard Behl

PSAAPG President, 2018-2019

James R. Weddle

April 18, 1931 - September 30, 2018

James (Jim) R. Weddle, born April 18, 1931 in Berkeley, California passed away September 30, 2018. A private interment service was held at Bakersfield National Cemetery.

Jim was preceded in death by his parents, Herman & Marjorie Weddle, brother Roger, and wife Alta Weddle, who passed in 1996 after a lengthy illness.

Jim is survived by his wife, Evelyn Hall Weddle whom he married in 1998, his daughter, Eilley Brandlin and husband Rick, and daughter Sarah Weddle Schaefer and husband Don. Grandchildren, George and Josephine Brandlin, Hypatia Luna and husband Jesse, daughter Inez, Zachary Kevorkian; together withhis step-children, Sammye Hall, Vanessa Wigton and husband, Don; his step-grandchildren, Erika Bahnik, husband Jean, son Christian and daughter Isabelle, Jacqulene Maegert, son Gabriel and daughter Mia, Brett Skinner and wife Aimie, Brandon Wigton, wife Kelly and daughters Cwynn, Ally & Lily, all of whom had a close and loving relationship as their grandfather.

Jim graduated from East Bakersfield High School in 1949. He attended U.C. Berkeley (Cal) for one year before enlisting in the USAF during the Korean War. He served in special weather intelligence at Elmendorf AFB in Anchorage, Alaska. During this time he met and married Alta Bailey in 1954. Upon completion of hismilitary service they moved to Berkeley, California. Using the G.I. Bill, Jim resumed his education at Cal, receiving a Bachelor or Arts degree in palentology in 1957. The year of his graduation came the birth of daughter Eilley, with a second daughter, Sarah, following two years later.

After graduation, Jim accepted a position as Junior Engineer with the State Division of Oil and Gas (DOG), and moved to Sacramento, California. He ended his career with the State as Chief Deputy of DOG in 1976.

Jim began his consulting business in Sacramento offering geology and property evaluation services to the oil industry. The majority of his business grew in Bakersfield and Los Angeles, so the family moved to Bakersfield where his business was incorporated as San Joaquin Energy Consultants (SJEC). With Alta's help in the office, he built a broad list of clients to whom Jim furnished geology, property tax, and environmental compliance, as well as property appraisals. SJEC became the largest independent property tax company in California representing over 60 small and large oil companies, including Chevron, Texaco, Mobil, and Berry Petroleum. Jim Retired in 1998.

His passion for reading and hobby collecting books for his library was well known. He was especially interested in Mark Twain and modern mystery writers. He served as a consultant to the board for the California State University of Bakersfield (CSUB) Library. Over the years, Jim was active in local charitable and civic organizations, including a Paul Fellow member of Rotary International, American Heart Association, American Cancer Association and Mercy Hospital Foundation Board.

Jim established two local scholarship funds in honor of his parents; Herman Weddle Scholarship Fund for the Geology Department of CSUB and the Marjorie Weddle Scholarship Fund with the Bakersfield Symphony Foundation. Contributions may be made to either of these scholarship funds in his honor.

This article presents some of the key investigations and conclusions that were done as part of a M.Sc. thesis in Geology at California State University, Long Beach:

Strain Variation Between the Monterey and Sisquoc Formations, Southern Santa Maria Basin, California, USA: Implications for Structural Assessment of Fold and Thrust Belts

By
Yannick Wirtz

The full thesis can be requested by contacting Yannick at: y.wirtz@gmail.com

ABSTRACT

Analysis of variation of fold strain at map-scale and outcrop-scale of the siliceous Monterey and Sisquoc formations in the southern Santa Maria basin, California provides insight into limitations of strain determination by construction of area-conservative balanced cross-sections. Diagenetic modification of these rocks allows strain quantification of rock intervals with high competence contrasts. Detailed strain analysis at map-scale shows significant variation in fold strain between rock types with shortening values ranging from 5.5 % to 21.1 %. Apparent shortening in the competent Monterey Formation is twice as high as in the overlying highly porous Sisquoc Formation. The large difference in apparent shortening suggests that the same amount of actual strain was accommodated by folding in the Monterey and horizontal compaction in the Sisquoc Formation, since there is no evidence of a detachment fault or major unconformity between the units. Strain analysis at outcrop-scale provides insight into how both units express such different shortening ratios without having an unconformity, or detachment fault between them.

INTRODUCTION

The reconstruction of the geometric and kinematic evolution of fold-and-thrust belts requires depiction of deformation mechanisms and quantification of shortening. Balanced cross-sections account for translational and rotational strain components by integrating surface and subsurface data across fold-and-thrust belts generally at regional scales. The construction of these sections produces geometric and kinematic models, illustrates the deformational history, and predicts structural traps for petroleum prospects in basin exploration (Suppe, 1980; Namson and Davis, 1988 a, 1988b; Mitra and Namson, 1989; Namson and Davis, 1990). Yet, balanced cross-sections have limitations because they do not account for the different mechanical behaviors of rocks and their deformation mechanisms at more detailed scales that may affect structural assessments in local regions within fold-and-thrust belts.

It has been shown that by focusing on particular scales, lithologies, and environmental conditions (e.g., pressure, temperature), significant differences can arise with respect to the deformational pattern (Snyder, 1987; Behl, 1992), the amount of shortening (Koyi et al., 2003), the variation in strain and structural style along strike (Carbonell et al., 2013), and interpretation of the kinematics and mechanics of emplacement of thrusts (Mitra, 1994; McQuarrie and Davis, 2002). Therefore, strain information derived from different scales and lithologies of contrasting physical properties may significantly improve our understanding of the different local structural styles.

Siliceous sedimentary rocks can exhibit very heterogeneous and contrasting physical properties. The initial composition of siliceous sediments are highly porous oozes of diatoms or radiolarians before undergoing significant and complex mechanical modification with burial diagenesis resulting in variations in physical rock properties (Isaacs, 1981). This opens up the opportunity to study the magnitude of strain variation across mechanically contrasting lithologies in fold-and-thrust belts at map-scale and outcrop-scale.

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This study quantifies and analyzes the variation of strain of the petroliferous Monterey and Sisquoc formations in the southern Santa Maria basin (SMB), California, USA, because they comprise siliceous strata of a distinct diagenetic stage. The results of this work provide an explanation for how distinct deformational styles between competence contrasting siliceous diagenetic rocks at formational- and outcrop-scale can exist without a detachment fault between them, and opens up new possibilities for prediction of geologic structures in the subsurface.

GEOLOGIC BACKGROUND

The part of the southern SMB examined in this study exposes siliceous strata of the Monterey and overlying Sisquoc formation over 340 km2. Two study areas were chosen to investigate strain in the southern SMB (Fig.1). Their location is within a structural province of regional contraction across the SMB that formed four anticlinal trends of 15-80 km in axial length and 2-3 km in structural relief. Regional-scale balanced cross-sections interpret the anticlinal trends to be fault-bend and fault propagation folds resulting from thrust ramps off thrust flats and a regional detachment at 11-14 km depths (Fig.1) (Namson and Davis, 1990).

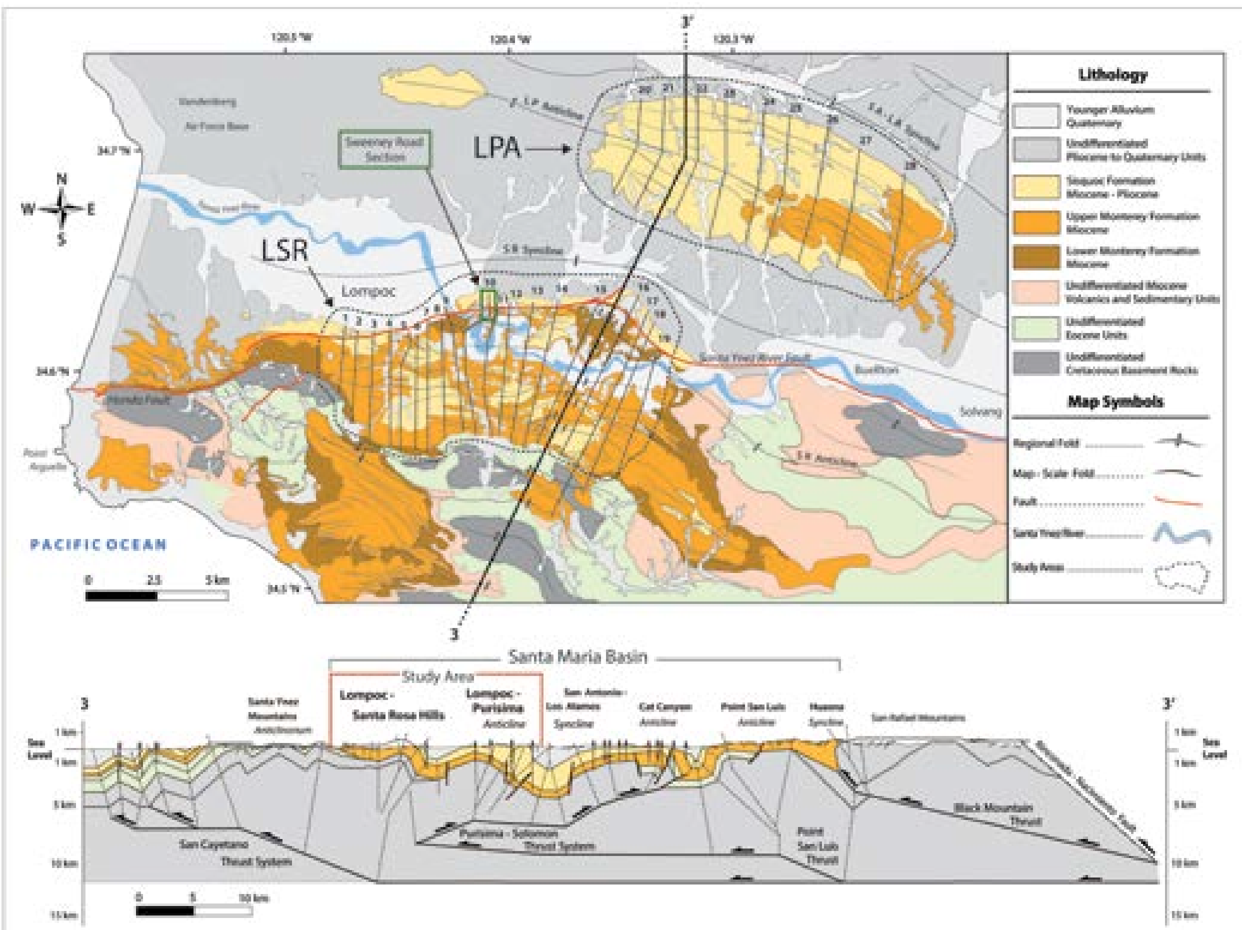

Figure 1: Geologic map (top) (modified after Dibblee, 1950; and Dibblee and Ehrenspeck, 1988a-e) of the southern Santa Maria basin showing the study areas, locations of cross-sections constructed in this study, and portion of cross-section 3-3' by Namson and Davis (1990) with full regional section (bottom) showing the full structural extend of the Santa Maria basin compared to the study area.

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In the study areas, the fold style diverges significantly from the regional fold belt of the SMB. The regional folds in the SMB have wavelengths of 5 to 10 km and axial lengths of up to 40 km (Fig.1). In contrast, the study areas are composed of localized east-west oriented folds with wavelengths ranging from 0.1 km to 3 km and axial lengths ranging from 0.5 km to 10 km. These folds are almost entirely confined to the upper Monterey and Sisquoc formations and just a few structures with regional axial lengths of over 10 km extend into adjacent units of younger or older age outside of the study area (Fig.1). Only a few regional folds underlie the highly folded Monterey Formation. In general, there are first order folds and above 10 km in axial length and part of major structures that involve older and younger rocks. Second order folds are 0.5 - 8 km in axial length and represent the majority of folds. Third order folds are 0.1 - 0.5 km in axial length and occur in smaller sets. Second and third order folds represent the majority of folds are confined to the upper Monterey and Sisquoc formations. Because of the spatial limitation of the folds to the described areas and the contrasting fold magnitude compared to the regional scale the two study areas will now be referred herein as the Lompoc - Santa Rosa fold belt (LSR) to the south and the Lompoc - Purisima Anticline fold belt (LPA) to the north (Fig.1).

Rocks of the upper, thinly bedded siliceous member of the Monterey Formation in the LSR display intraformational deformation at outcrop-scale (Snyder, 1987; Gutiérrez-Alonso and Gross, 1997). This deformation includes a variety of different types of detachment folds and fault-propagation folds (Snyder, 1987) that are interpreted to be the result of blind thrusts splaying off detachment horizons at depth and bedding-plane detachments themselves folded progressively during deformation (Gutiérrez-Alonso and Gross, 1997).

The Monterey and Sisquoc Formations

The Monterey and Sisquoc formations were deposited during the Miocene to early Pliocene prior to the widespread regional contraction and have accommodated tectonic shortening with contrasting deformational styles in different locations and stratigraphic intervals (Snyder et al.,1983; Snyder, 1987; Gutiérrez-Alonso and Gross, 1997). Even within a single outcrop, and therefore identical tectonic conditions, beds can provide widely different structures and individual styles of tectonic deformation. This is due to a complicated interplay between the deformational and the diagenetic history of the bedded siliceous sedimentary rocks that affects their deformational style (Snyder et al., 1983; Snyder, 1987; Behl, 1992). The Monterey and overlying Sisquoc Formations in the study area preserve siliceous sediments in a complete spectrum of diagenetic stages. The degree of the diagenetic stage is controlled by the initial sediment composition and temperature with depth (Fig.2). This enables dramatic variations in lithologies even within a single outcrop from opal-A (diatomaceous sediments composed of X-ray amorphous silica) to opal-CT (metastable silica composed of poorly ordered, hydrous cristobalite and tridymite) to quartz bearing rocks (Isaacs, 1981). In general, the lithologies in the stratigraphically higher Sisquoc Formation are all composed of opal-A phase diatomaceous sediments with alternating detritus content (Fig.3). In contrast, the lithologies in the underlying upper Monterey Formation are highly heterogeneous and progressively composed of more opal-CT phase rocks of higher competence down-section (Fig.3). For simplicity, all porous opal-A diatomaceous rocks will be termed as diatomite, and all hard to brittle opal-CT diagenetic rocks will be termed as chert/porcelanite, regardless of variations in their detritus content.

Variations in physical properties of these rocks that influence their distinct structural behavior as a result of initial sediment composition and diagenetic modification have been described as mechanical stratigraphy (Gross et al., 1997). In the study areas, the upper Monterey Formation is largely composed of thinly bedded intervals of incompetent, porous diatomite and competent hard to brittle chert/porcelanite. The overlying Sisquoc Formation is less diagenetically altered and composed of thick bedded, highly porous diatomite (Fig.3). The great mechanical anisotropy between the Sisquoc and the upper Monterey Formation provide the basis for development of different deformational mechanisms in close proximity, including both consumption of strain via volume reduction in diatomites (pure shear) and complex interplay of flexural-slip, folding and faulting within interbedded diatomite and chert/porcelanite (simple shear).

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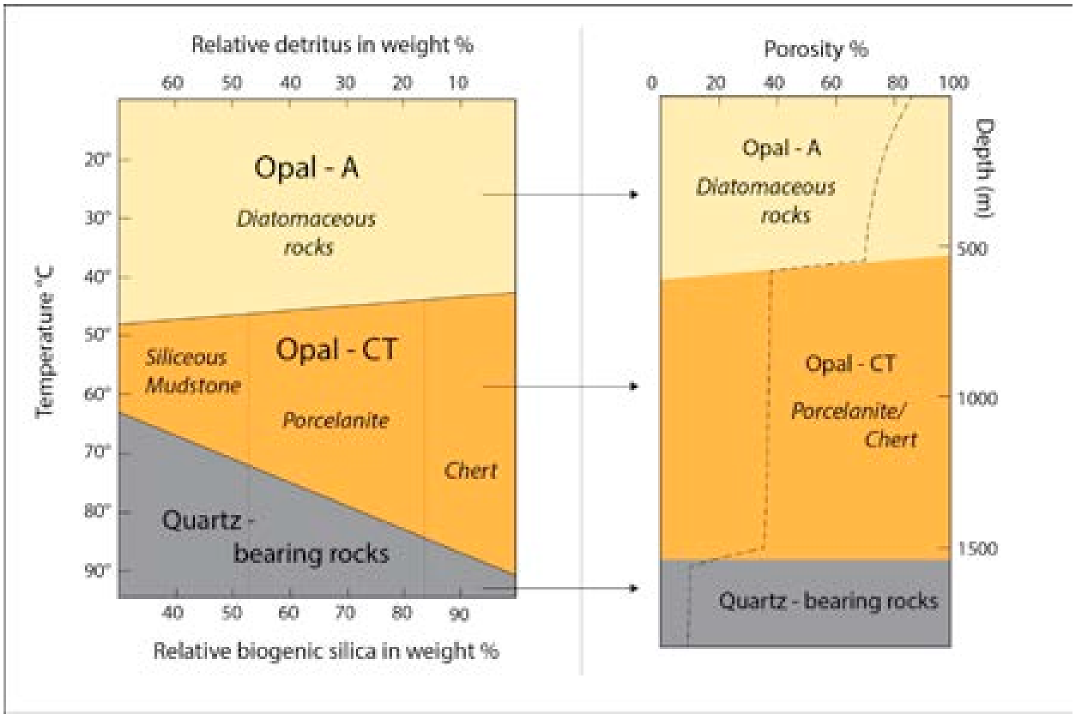

Figure 2: Silica phase changes during diagenesis and associated lithologies (left) (modified after Isaacs, 1981 and Behl, 1992) and stepped changes in porosity with depth (right) (modified after Isaacs, 1981).

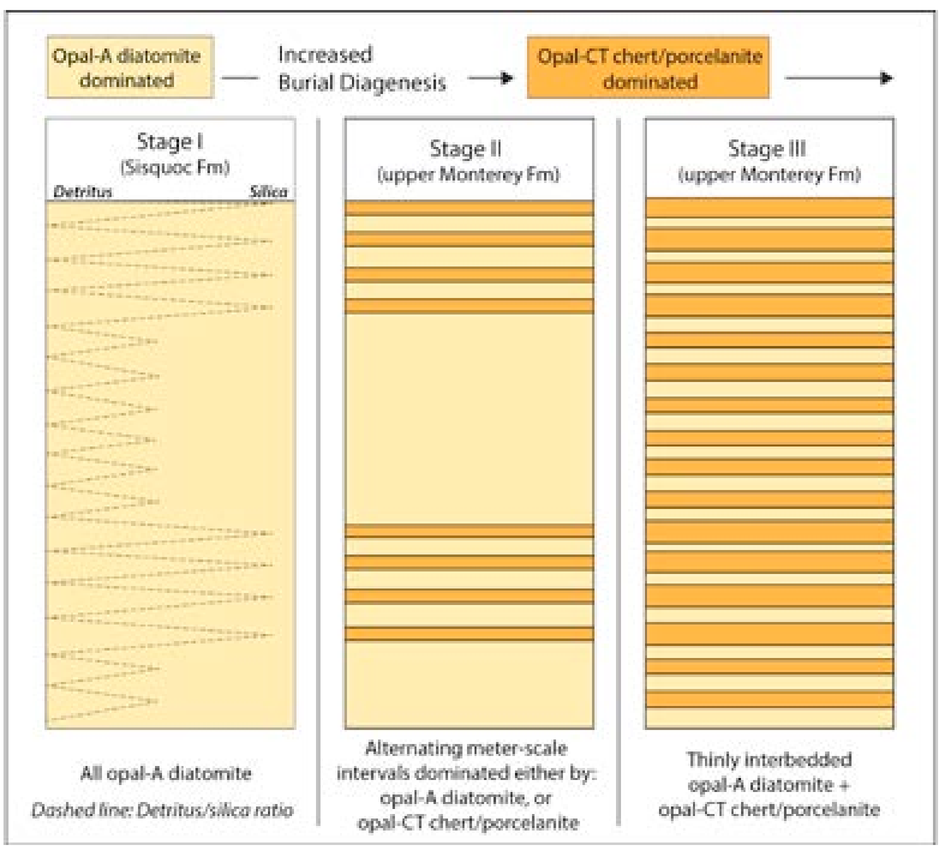

Figure 3: Sketch of diagenetic modification of a representative section in the upper Monterey Formation. Note that the primary composition (silica/detritus) shown in stage I controls the kinetics of silica phase transitions shown in stages II and III.

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STRAIN ANALYSIS

Map Scale Strain Analysis

Tectonic shortening was quantified in the upper Monterey and Sisquoc formations in order to address the impact of lithology on deformational behavior and better depict variation of strain intensity with space and scale. Nineteen cross-sections across the upper Monterey and Sisquoc formations in the LSR, and nine cross-sections across the LPA were constructed to generate the key data set for shortening estimates and fold geometry description (Fig.1). (see methodologies for shortening estimates and all cross-sections in full thesis.)

The data show significant strain variation along strike of the fold axes over short distances (Fig.4). In the LSR, shortening values range from 5.5 % (profile 6) to 21.1 % (profile 10). From the western to the eastern part of the LSR, areas of high strain are separated by areas of low strain. In general, three high-strain areas occur in the most western, in the central, and the most eastern part (Fig.4). Between these areas of higher strain, shortening significantly decreases over distances of just a few kilometers. In the LPA, shortening values range from 4.7% (profile 21) to 16.8 % (profile 28). The magnitude of shortening is distinctly lower in the western part and higher in the eastern part. Significant increase in strain occurs, like in the LSR, over just a few kilometers of along-strike extent (Fig.4). The contribution of shortening in the Sisquoc Formation and shortening in the Monterey Formation to the total shortening shows a mean ratio of 0.52 : 1 in the LSR and 0.48 : 1 in the LPA between shortening expressed in the Sisquoc Formation vs. Monterey Formation shortening (table 1 in full thesis).

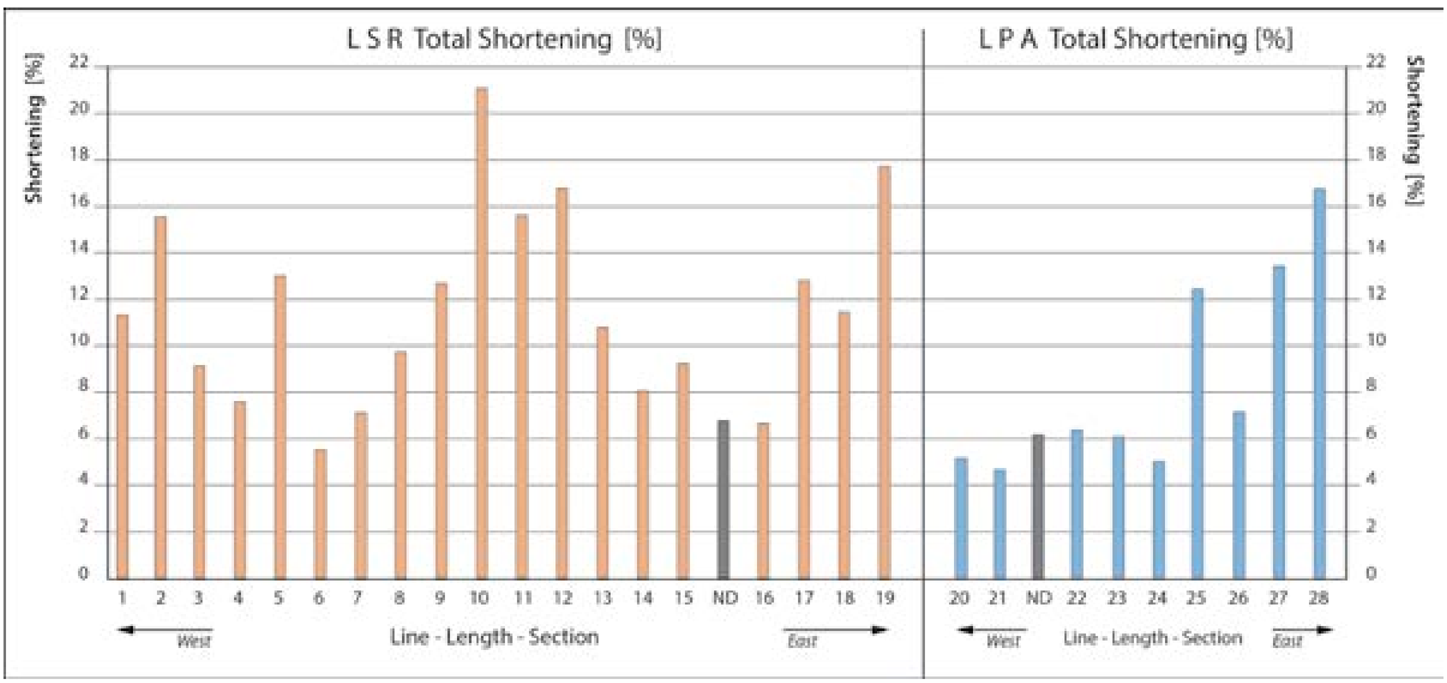

Figure 4: Histogram of shortening estimates in the LSR (orange) and LPA (blue). Shortening estimates of the specific transects by Namson and Davis (1990) are shown in grey.

In both study areas, results show a negative trend between the amount of shortening and the amount of Sisquoc Formation exposure, and a positive trend between the amount of total shortening and the amount of Monterey Formation exposure to the total profile length, respectively. In other words, low shortening rates are observed in sections with high exposure of Sisquoc Formation, and high shortening rates are observed in sections with few exposures of Sisquoc Formation. Transects with mostly Monterey exposures show the highest shortening rates and transects with mostly Sisqouc exposures show the lowest shortening rates (Fig.5).

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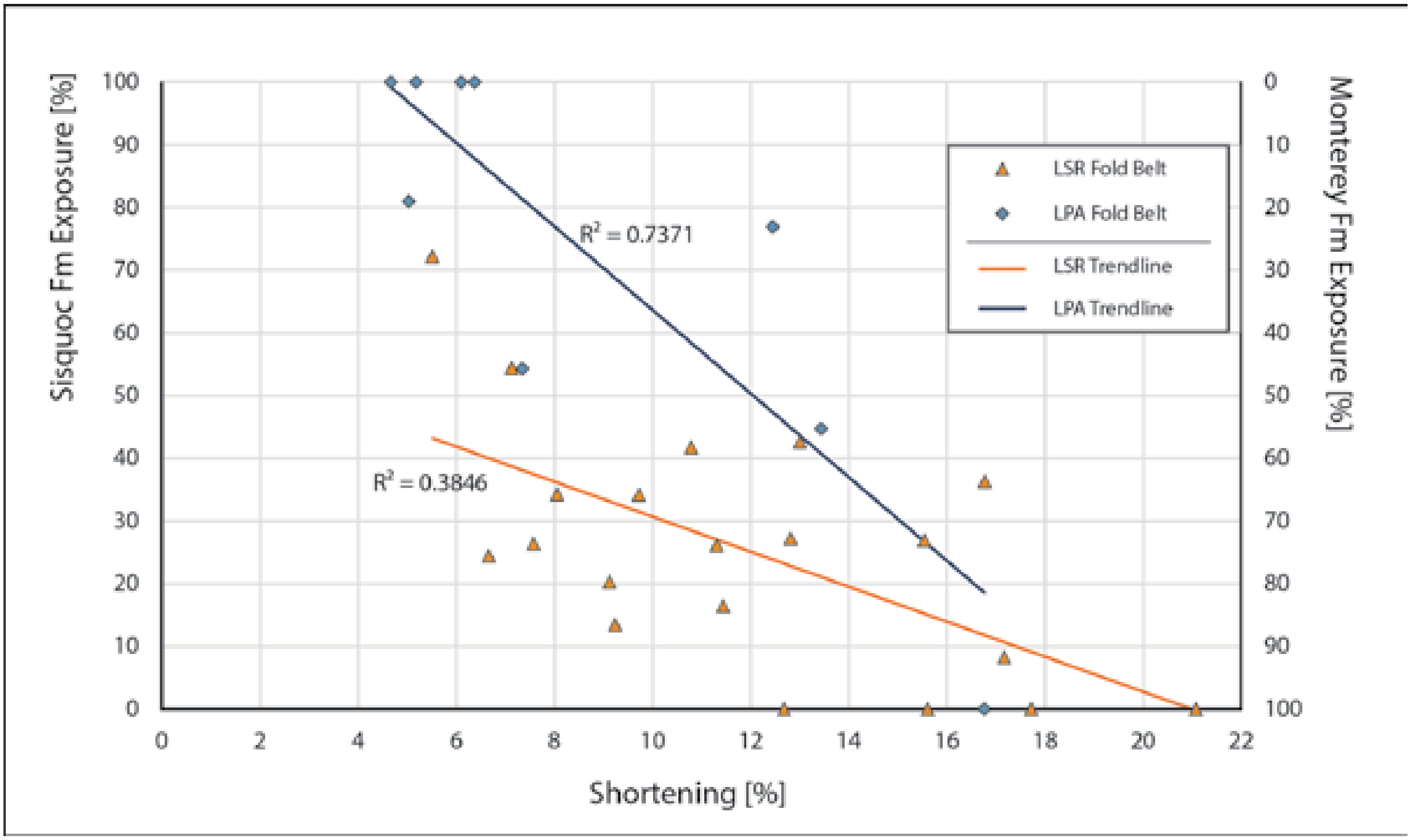

Figure 5: Correlation of the formational ratio (Sisquoc : Monterey) used during cross-section construction over shortening results in LSR (orange) and LPA (blue).

Outcrop Scale Strain Analysis

Structural mapping was performed at Sweeney Road, near Lompoc, California (Fig.1). The investigated section at Sweeney Road is folded into an anticline to the north and a syncline to the south. The anticline/syncline pair is folded into concentric and chevron type folds with fold angles of 68° for the anticline and 98° for the syncline, with steeply north-dipping axial planes (Fig. 6,7).

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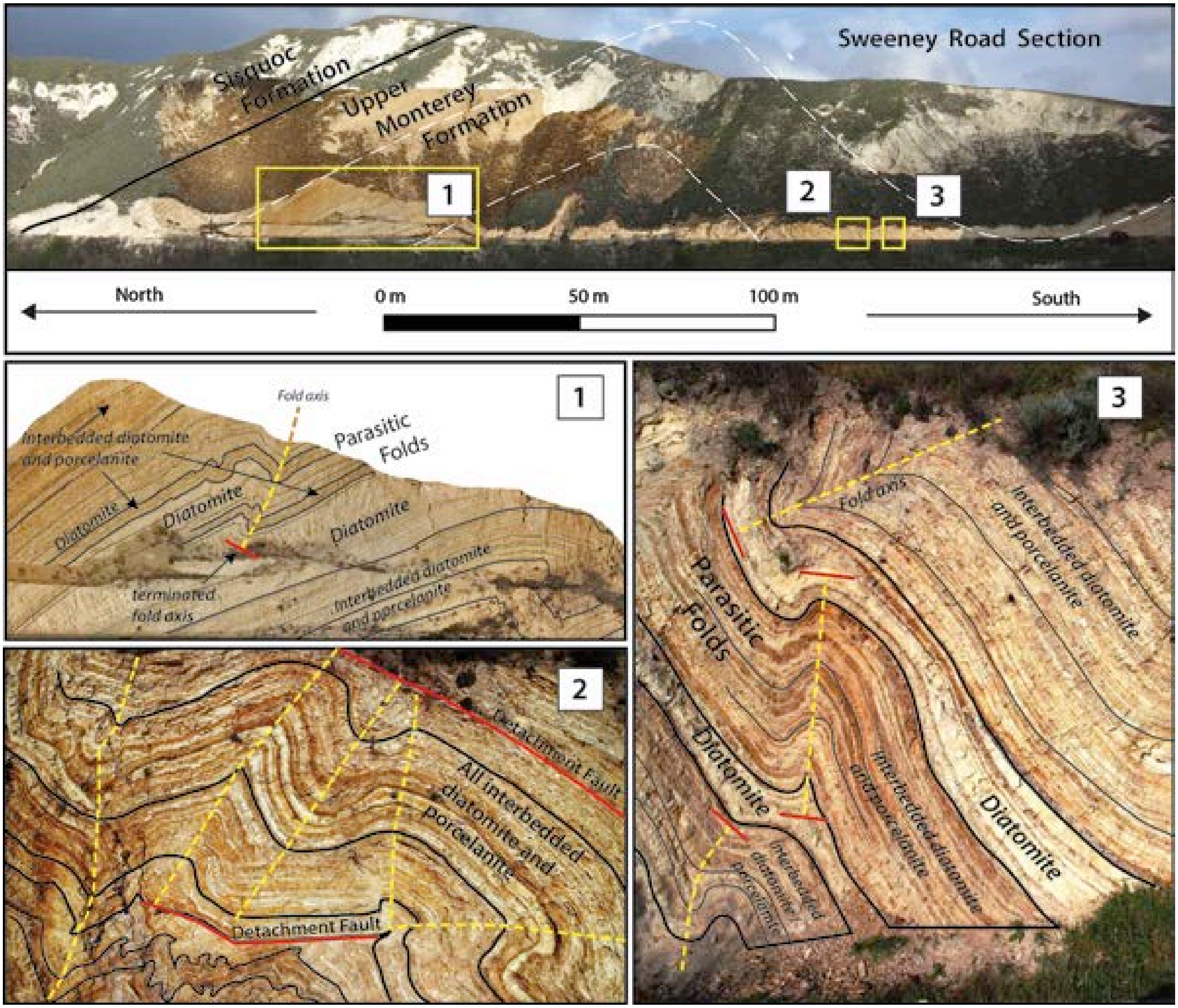

Figure 6: Photos of Sweeney Road section (top picture) that were used for outcrop-scale structural analysis. White dashed line showing general anticline/syncline pair geometry. Details of deformation are shown in boxes 1-3. Yellow dashed line showing fold axes of disharmonic parasitic folds that terminate within the diatomite dominated layers and disharmonic buckle folds that terminate at a detachment surface. Note the thickness variations in the diatomite layers in (1) and (3).

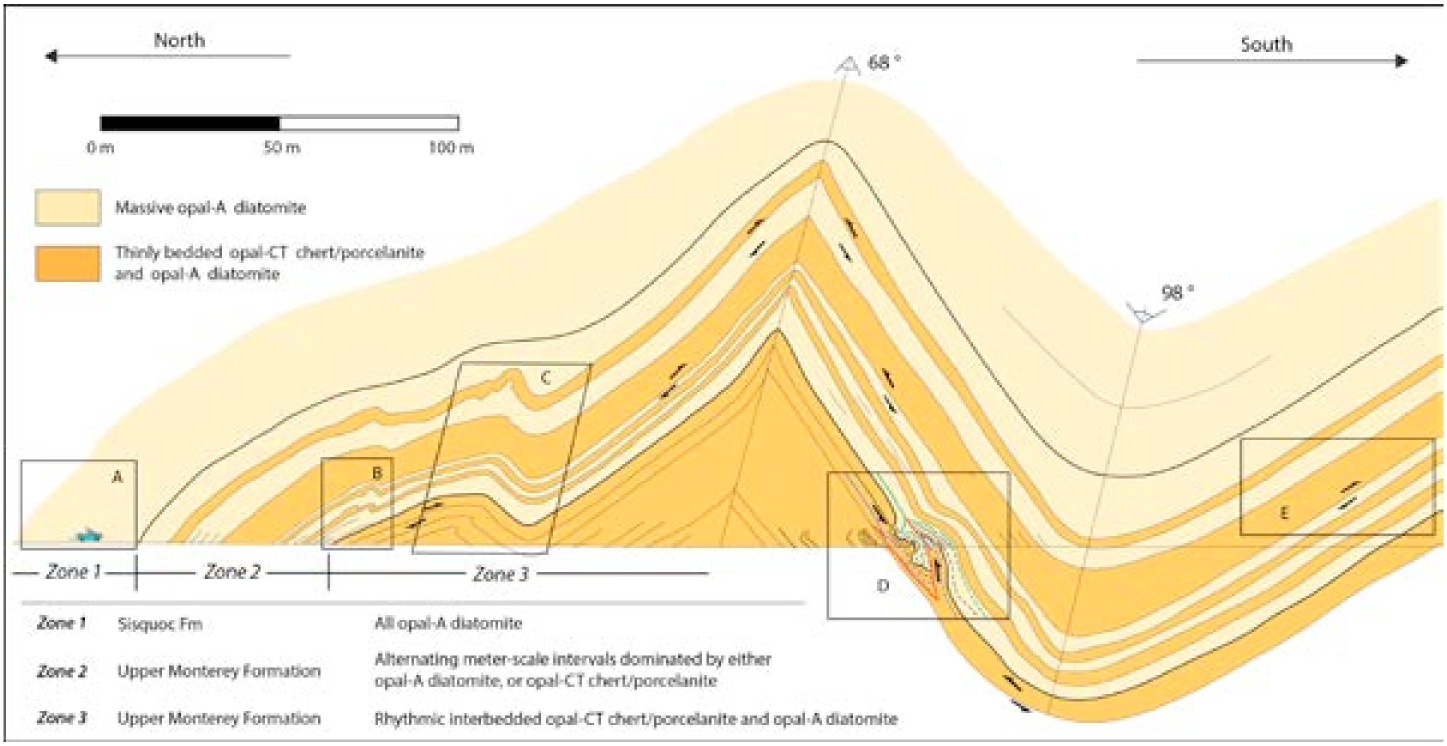

Figure 7: Map of fold structures of the Sisquoc Formation and upper Monterey Formation at Sweeney Road. Boxes A-E show the different structural styles including massive beds (box A), disharmonic folds (box B), harmonic folds (box C), limb faults and buckle folds (box D), and pure flexural-slip (box E). Note that zones 1-3 exhibit a mechanical stratigraphy.

The relative distribution of diatomite to chert/porcelanite changes progressively throughout the Sweeney Road section with pure diatomite in the Sisquoc Formation to chert/porcelanite dominated intervals in the upper Monterey Formation (Fig.7). Three zones of distinct contrasting mechanical properties were identified. Zone 1 is in the lower Sisquoc Formation and mechanically homogeneous. The main lithology is diatomite. Zone 2 is the initial diagenetic transition zone in the upper Monterey Formation and is composed of alternating meter-scale intervals dominated by either diatomite, or chert/porcelanite. Zone 3 exposes thinly bedded upper Monterey Formation that is characterized by rhythmic interbedded chert/porcelanite and more porous and detritus rich diatomaceous sediment (Fig.7). The three identified zones are consistent with the three siliceous diagenetic stages that were explained in figure 3. The most prominent outcrop-scale structures were investigated at five locations each with different mechanical and/or map-scale structural settings (Fig.7 boxes A-E) in order to investigate their influence on the deformation. The first location (Fig.7 box A) is located on the north-limb of the anticline and lithologically in zone 1 and composed entirely of diatomite of low competence. No outcrop-scale structures were observed within this domain. The second location (Fig.7 box B) is structurally located on the north-limb of the anticline and is lithologically in a diagenetic transition zone with diatomite dominated to chert/porcelanite dominated rocks through the section (zone 2). The most prominent structures are Z-shaped folds with differing scales and wavelengths. Folds occur through the more competent beds that are dominated by cherts and porcelanites. The porous diatomite intervals are also displaced by the folds, but the folds vanish away from the folded chert/porcelanite dominated package (Fig.6; Fig.7 box B). Fold wavelengths differ depending on layer thickness. Thicker competent packages display longer fold wavelengths than the thinner competent packages in the more massive diatomaceous intervals (Fig.7 box B and C). The third location (Fig.7 box D) is structurally located on the south-limb of the anticline and north-limb of the syncline). Lithologically it exposes a thick package of thinly-bedded chert/porcelanite dominated lithologies towards the center of the anticline (zone 3) and thinner packages

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of chert/porcelanite dominated lithologies within a thicker interval of incompetent diatomite towards the center of the syncline (zone 2). The largest and most prominent outcrop-scale structure within this domain is a low-angle (relative to bedding) limb thrust fault that transects a more competent section of chert/porcelanite dominated rocks and penetrates into the more incompetent section of diatomite dominated rocks via a hanging-wall cutoff. This geometry produced a variety of lower order folds and internal footwall buckle folds and a hanging wall fault-bend fold (Fig.7 box D). The structural position of the fourth location is on the south limb of the syncline and inhabits zones 1-3. Similar to the first location, no major outcrop-scale structures were observed within this domain.

DISCUSSION

A deformation model is presented based on detailed analysis of strain variations between mechanically homogeneous diatomite of the Sisquoc Formation and the thinly and mixed bedded diatomite and chert/porcelanite of the upper Monterey Formation. The model integrates observations made at map-scale and outcrop-scale and may have implications for predicting structures in the subsurface.

Interpretation of Strain Differences Between the Sisquoc Formation and Upper Monterey Formation

Strain analysis results show that measured shortening fluctuates up to 15.6% in the LSR and 12.1% in the LPA, respectively, over sub-regional scale distances (Fig.4) suggesting that the amount of measured shortening strongly relates to the predominant lithology of the formation that was used for structural data. Shortening in the thin bedded and more competent upper Monterey Formation is found to be twice as high as in the overlying, thick bedded, and less competent Sisquoc Formation.

Three possible scenarios may explain these strain variations: One possibility is an unconformity between the Monterey and the Sisquoc Formation. An uplift event during the late Miocene Rafaelan orogeny is documented through localized erosional unconformities at the base of the Sisquoc Formation in the San Rafael Mountains about 40 km to the north (Dibblee, 1950) and in the Santa Maria basin along many anticlines (Dumont and Barron, 1995). Although there is some evidence for localized vertical movement and erosion, there is no evidence for an unconformity at the outcrops analyzed in this study and no indication in the surface mapping of the study area for an unconformity (Dibblee, 1950) that could discretely separate beds of different strain histories. Furthermore, most widespread shortening occurred after the deposition of the Sisquoc Formation (Dibblee, 1950). Therefore, the contact between the Sisquoc Formation and the Monterey Formation is probably conformable and tectonic shortening between both units is assumed to be relatively identical.

A second possibility is that the two units are separate structural systems and decoupled via a detachment fault. In this scenario, the Monterey would undergo deformation by folding while the Sisquoc Formation would undergo less deformation with slip being consumed by a basal detachment fault instead of progressively folding in the Sisquoc Formation. Not supporting this explanation are map-scale fold axes staying consistent across the contact between Monterey and Sisquoc Formations without significant changes in orientation of bedding strike and dip. Furthermore, no regional detachment horizon between the Sisquoc and the Monterey Formations has been mapped by previous workers (Dibblee, 1950; 1988 a-e; 1993 a,b), or observed during fieldwork in this study.

A more likely third possibility relates to the different mechanical rock properties between the different siliceous diagenetic stages (Fig.3). In the following, a new deformation model based on observation of the structural behavior of the different siliceous diagenetic stages during contraction will be presented: In the study areas, diagenetic modification resulted in a thin-bedded, mechanically contrasting and more competent upper Monterey Formation, and a thick-bedded, mechanically homogeneous, highly porous and less competent overlying Sisquoc Formation. Strain quantification at outcrop-scale and micro-scale between different silica phases has already shown that the fold strain of competent chert/porcelanite intervals at outcrop-scale is much higher than fold strain of interbedded diatomites, but the missing fold strain (simple shear) is accommodated by layer-parallel strain

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(pure shear) in the diatomite (Behl, 1992). Therefore, strain between different silica phases can be recorded via different strain mechanisms so that their total shortening budgets still match. The deformation model presented here suggests that the same amount of strain was recorded by the upper Monterey and Sisquoc formations, but with different mechanisms. This strain is displayed by open to close folding and faulting in the brittle diagenetic rocks of the Monterey, but by horizontal compaction and gentle to open folding in the diatomaceous Sisquoc Formation (Fig.8). Therefore, total fold strain at sub-regional scales is best measured by restoring fold structures of the upper Monterey Formation because it is mechanically competent enough to respond to stress via folding and not horizontal compaction like the Sisquoc Formation. Representative sections for the Monterey Formation in the two study areas show 21.1% overall shortening in the LSR-, and 16.8% overall shortening in the LPA fold belt, respectively. A structure contour map from a representative area in the LSR fold belt was generated using the cross-sections created in LithoTect (Fig.8 - top right). The map shows short wavelength folds in areas with Monterey Formation surface exposure east of profile B-B' (Fig.8). These folds vanish towards the west and transition upsection into larger wavelength folds documented in the Sisquoc Formation exposed at the surface (Fig.8). The structural style of tighter folding in the Monterey Formation should continue in the subsurface where covered by the Sisquoc Formation as shown in profile B-B' (Fig.8).

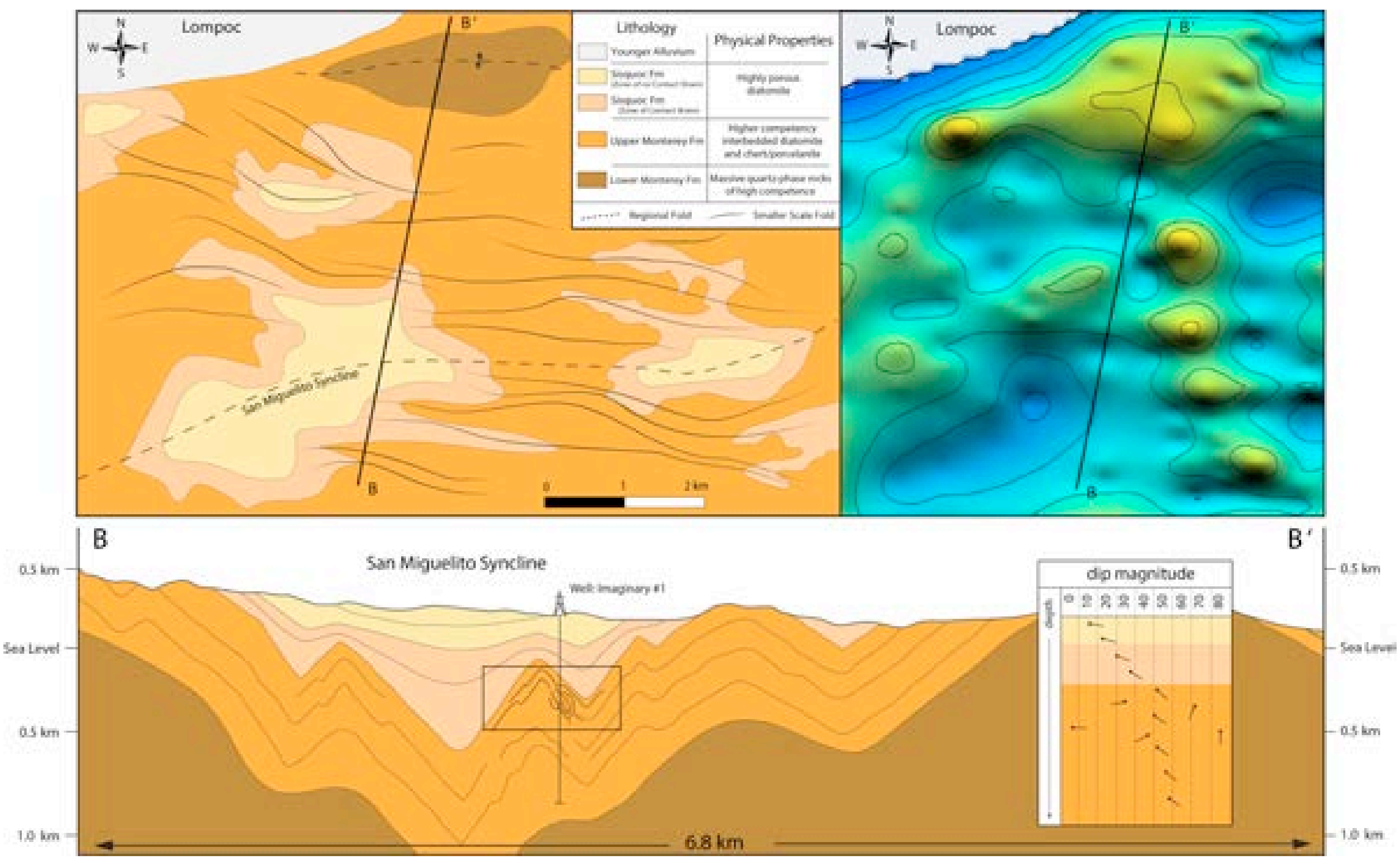

Figure 8: Generalized geologic map (top left) and interpretation of deformation mechanisms (cross section B-B') in the Monterey and Sisquoc formations. Note the three different folding patterns developed across the geologic units: (1) close folding and outcrop-scale folding along limbs of tight folds in the upper Monterey (orange), zone of upper Monterey contact strain and open folding in the lower Sisquoc Formation (pink), and zone of no contact strain and broad folding in the upper Sisquoc Formation. Structure contour map of projected upper Monterey and Sisquoc contact (top right) created using line-length-sections 2-14. Note the tight folding in the areas of Monterey dominated surface data in the east and the broad to open folding in the areas of Sisquoc dominated surface data in the west. On the cross section an imaginary well predicts scattered dip magnitudes within high-angle limbs in the upper Monterey Formation that represent deformation at outcrop-scale.

(Continued on next page)

The observations and interpretations made here show that significant fold strain variation can occur due to differences in rock rheologies at formational scale. This is expressed laterally along the surface by either climbing up-section into the Sisquoc Formation or dropping downsection into the Monterey Formation (Fig.8). The large observable strain contrast is due to the extreme difference in competence and rheology of the primarily diatomaceous Sisquoc Formation and the chiefly cherty/porcelanitic Monterey Formation. The strain contrast effect on the construction of cross-sections would be much smaller in non-siliceous rocks with smaller competency contrast. This highlights that competence contrasts of geologic units can be an important component in constructing and assessing structural models in different local sections of sedimentary basins.

Interpretation of Outcrop-Scale Structures

In the upper Monterey Formation a variety of structures and deformational styles are observed. The most common structures are parasitic S- and Z-type folds along the limbs of the folded anticlines and synclines (Fig.6,7). Parasitic folds with Z-type vergence (looking east) were observed on the north-limb of a map-scale anticline (Fig.7, box B and C). There are many lower order parasitic S-type folds on the south-limb of the anticline (Fig.6) and an out-of-the-syncline thrust fault intersects the S-type folds. This thrust fault is the dominant counter clockwise shear structure on this limb (Fig.7, box D). It is interpreted to detach from a competent section of dominantly interbedded chert/porcelanite and diatomite, and penetrates into an incompetent section of dominantly diatomite via a hanging-wall cutoff. This produced a domain of lower order buckle folds in the footwall and a hanging-wall fault bend fold (Fig.7, box D). The fault related folds likely developed here instead of parasitic S-type folds. Slip within these locations is transported via the bedding plane detachment faults out of the map-scale fold hinges creating a high strain situation expressed by small faults and buckling of the thinly bedded upper Monterey Formation instead of progressive folding. However, the parasitic folds and faults related buckle are the result of shear decoupling mechanisms during flexural-slip deformation along the bedding planes. Therefore, the shear direction of parasitic folds and fault-related folds suggest that outcrop-scale folding occurred during map-scale folding and that fold and fault strain at outcrop-scale resulted from shear decoupling is not additive to the total strain at map-scale.

On the south limb of the syncline at Sweeney Road, no outcrop-scale structures were observed (Fig.7 box E). These sections are representative of the majority of the exposures in the upper Monterey Formation throughout the LSR. Field work identified only few locations with outcrop-scale structures. The Sweeney Road section is located within the tightest folds across the entire LSR in the upper Monterey Formation. The outcrop-scale structures are not pervasive and probably only occur along the tight map-scale fold limbs where diatomite and chert/porcelanite coexists in thin beds and alternating packages of different thickness (Fig.6,7). Dip-magnitudes of wells drilled through the tightly folded upper Monterey Formation are predicted to display inconsistent dip-angles that represent the deformation at outcrop-scale (Fig.8). Therefore, regional structural subsurface modelling requires caution in picking representative dip-angles from dip-meters that transect tightly folded upper Monterey Formation. In gently folded sections the dip-meters are expected to be consistent. On the north-limb of the anticline at Sweeney Road, parasitic folding is both harmonic, and disharmonic (Fig.6, and 7 box B). This is interpreted to result from different deformation mechanisms (simple shear of the chert/porcelanite dominated interbeds and pure shear of the diatomite dominated packages) bedding thickness, and interbedded competence-contrasting beds.

There are two situations that develop harmonic and disharmonic folding. First, under the influence of flexural-slip deformation along the bedding planes, thinly interbedded chert/porcelanite dominated intervals can develop disharmonic folds above a bedding plane detachment (Fig.6). Slip on the detachment surface provides the fold shortening to the higher beds and the fold axis terminates downward into the detachment. If no detachment surface is present, folding becomes harmonic without termination of the fold axes (Fig.6). Secondly, if competent chert/porcelanite dominated interbeds are separated by a sufficiently thick and incompetent diatomaceous mechanical layer, the fold vanishes and the individual competent interbeds behave mechanically detached from each other

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and develop their own dominant wavelength without a fault separating the individual folds (Fig.6,7). This is accompanied by significant thickness variations and fold termination through the diatomite layers (Fig.6,7). If competent chert/porcelanite dominated interbeds are separated by a relatively thin incompetent mechanical layer, but in close proximity to each other relative to their own thickness, then the fold of the competent interbeds reaches the next package of competent interbeds and the folding becomes harmonic (Fig.7 box C). This interpretation suggests a relationship between the magnitude of folding in the deformed chert/porcelanite dominated intervals and the thickness of intervening diatomite intervals that depends on how much local compaction can be absorbed by the diatomite without having to displace it. As a consequence, very small amounts of buckling can be harmonic between individual beds separated by only centimeters, but as the amplitude of folds increases, thicker stratigraphic units of porous diatomite would be required to keep folding from becoming harmonic. Therefore, in zone 2 (Fig.7), folding within a thinly interbedded chert/porcelanite dominated interval tends to be harmonic because of the thin diatomaceous interbeds, but folding becomes disharmonic as subsequent packages of thinly bedded chert/porcelanite can be folded in an out-of-phase geometry because of the thick, intervening beds of diatomite (Fig.6, and 7 box B and C). The deformation of incompetent layers that undergo folding as a result of the folding of adjacent competent layers has been described as contact strain (Frehner, 2008). In incompetent rocks with sufficient distance from the main fold, the folding becomes negligible and simple shear translates into pure shear and no contact to fold strain. The documented deformation mechanisms (pure shear and simple shear) at outcrop scale suggest that the mechanical stratigraphy is the main controlling element for decoupling along the Sisquoc- to upper Monterey Formation diagenetic boundary.

The existence of zones within incompetent diatomaceous packages that translate fold strain into volumetric strain (zones of contact strain into zones of no contact strain) detach the fold strain at outcrop-scale and provide an explanation for how the distinct deformational styles between the purely diatomaceous Sisquoc Formation and the thin-bedded chert/porcelanite dominated upper Monterey Formation can exist without a detachment fault between them at formational scale (Fig.8). At outcrop-scale, this relationship is shown to be related to contact strain transmitted upwards from the underlying Monterey folding. Therefore, the map-scale structural style in the study areas progressively changes up-section from open to close, sub-regional folding in the upper Monterey Formation, to zone of contact strain folding in the lower Sisquoc Formation, to regional folding with no contact strain in the upper Sisquoc Formation (Fig.8).

CONCLUSION

Several key conclusions arise from strain analysis of the Monterey and overlying Sisquoc formations in the southern SMB:

1. Significant fold strain variation along strike can occur due to differences in rock rheologies at formational scale.
2. Mechanical stratigraphy is the main controlling element for decoupling along the Sisquoc- to upper Monterey Formation diagenetic boundary.
3. Parasitic folding at outcrop-scale is not pervasive and only occurs within tight map-scale anticline/syncline pairs. Its shear direction suggests that this deformation is coeval with the map-scale folding.
4. Thick diatomaceous intervals within stratigraphic sections can terminate the fold strain at outcrop-scale by transferring fold strain into volumetric compaction.
5. Distinct deformational styles can coexist in close proximity without a fault detachment between the purely diatomaceous Sisquoc Formation and the thin-bedded chert/porcelanite dominated upper Monterey Formation.

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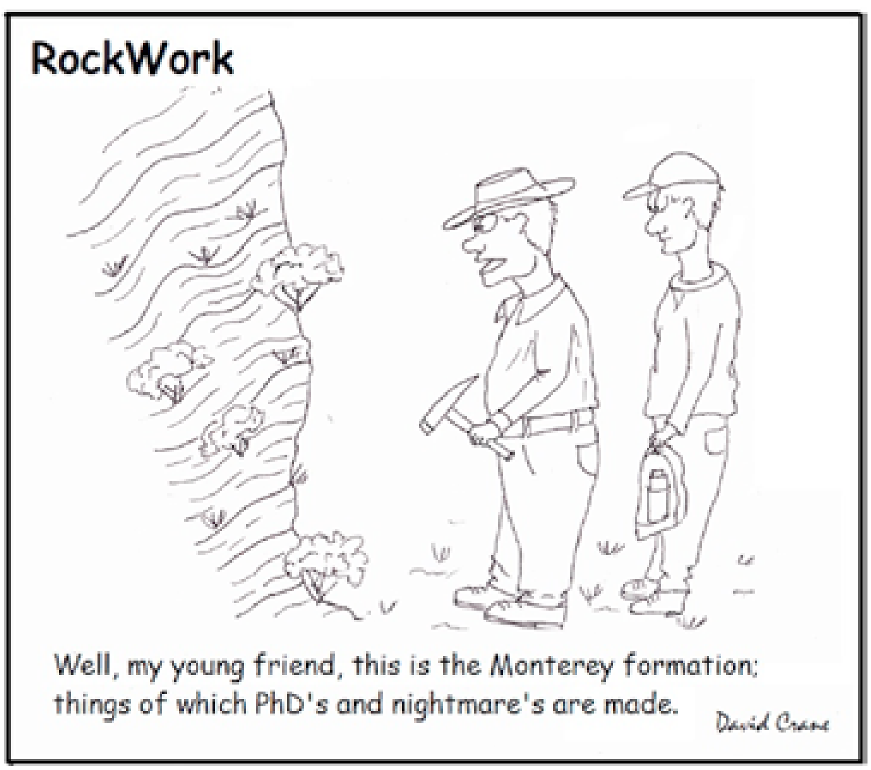


Biography of Yannick Wirtz

Yannick Wirtz is a California geologist. His research interest focuses on structural geology, petroleum systems, and active tectonics in Southern California. Yannick is currently working for Earth Consultants International (ECI), a geologic consulting firm based in Santa Ana, CA. He completed an MS in Geology at California State University, Long Beach under the guidance of Richard Behl, Nate Onderdonk, Thom Davis, and Jay Namson after completing a BS degree in Applied Geology at RWTH Aachen University of Technology in Germany. Yannick originally came to California in the spring of 2011 to go surfing and to conduct climate research at UC Irvine as part of his BS degree thesis. He then went on to work as an intern for ECI. At ECI he gained experience in southern California geology and engineering geology practice. In Fall 2013, Yannick started an MS program in geology at California State University, Long Beach where he worked with the Monterey and Related Sediments (MARS) research group, an industry affiliates program on the Monterey Formation incorporating field methods, structural geology, sedimentology, and tectonics in his research. His research project was sponsored by grants received from AAPG, GSA, and the MARS industry affiliates. Yannick was on the Long Beach team at the 2014 AAPG Imperial Barrel Award competition where he and his colleagues utilized petroleum industry software, and an understanding of petroleum systems to analyze the prospectivity of a frontier region and present their findings and recommendations to a panel of industry experts. In 2016, Yannick returned to ECI as a full time consultant. He has been active in professional societies throughout his academic and professional career and presented, and lead field trips at several science symposiums at California State University Long Beach, local geological societies, the National GSA Conference in Baltimore (2015), Pacific Section AAPG conferences (Bakersfield 2014, Oxnard 2015, Las Vegas 2016, Bakersfield, 2018), and the Tectonic Studies Group conference in London (2016).

Looking to the Future & Building the Bridge

Congratulations to the new faces of the PS AAPG positions:

YP Coordinator - Erica Rubino

Student Chapter Liaison - Cole Heap

PSAAPG Membership Directory

The PSAAPG website will have a members-only password-protected membership directory available as of March 1, 2018

Please email greg.thompsn@gmail.com if you do not want your name listed. There will also be a checkbox for this on the PSAAPG membership renewal form that goes out before the end of this year.

MUNGER MAP BOOKS

The CA Well Sample Repository is seeking donations of MUNGER MAP BOOKS

The collection is incomplete, so any donations would be kindly appreciated! Please contact Larry Knauer at laknauer@aol.com

Oil Patch Veterans Stay Connected at Luigi's!

Clockwise (from left to right): Jack Kappeler, Walt Dunbar, Ed Tilbury, Chuck Ruhl, Jim Kurfess

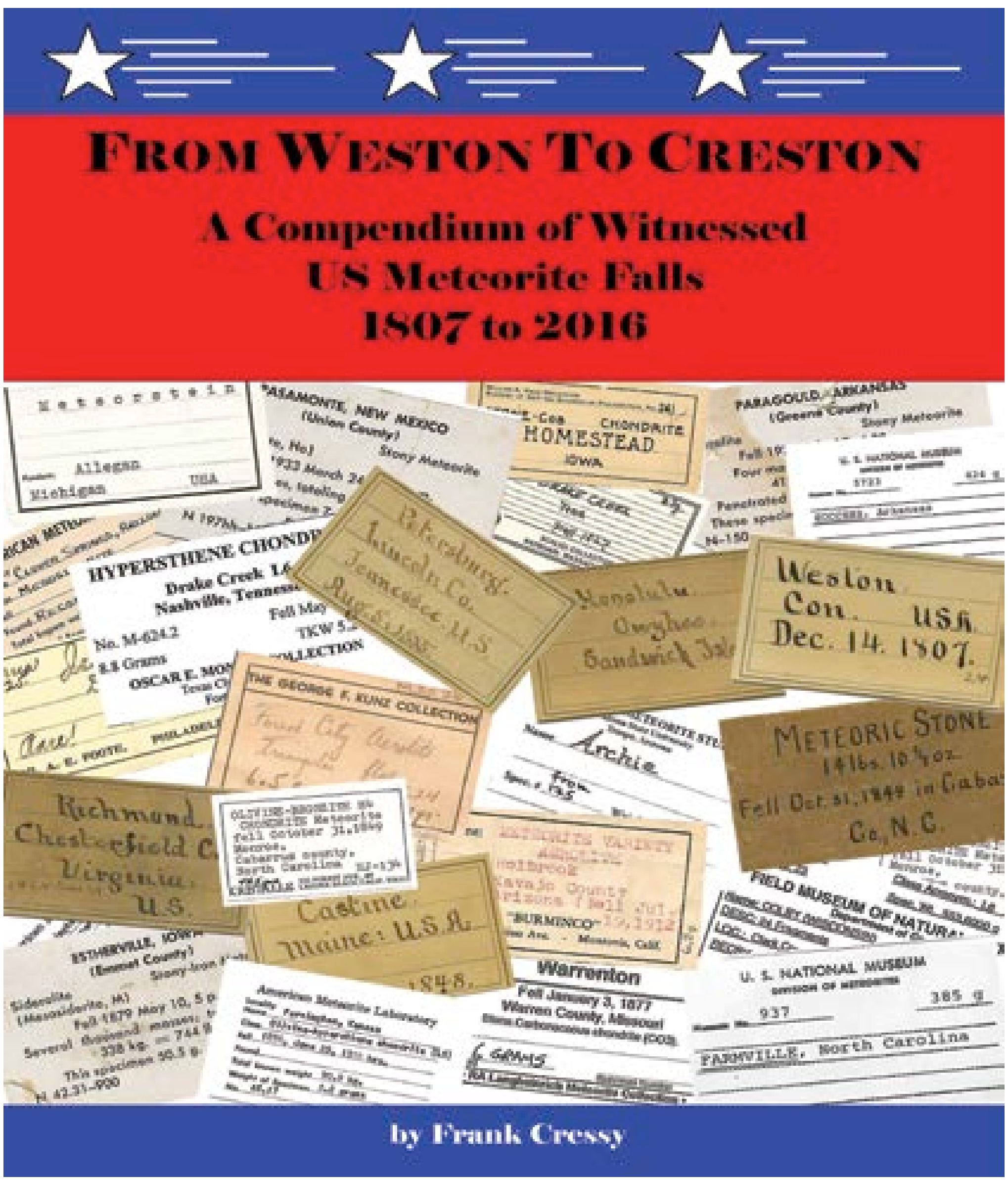
What a delicious tradition! This dapper lunch crew has been gathering at Luigi's every Wednesday to enjoy a meal together. They appreciate the great company and the reminiscing of their shared memories of the good 'ole oil patch days. All of the shenanigans transpire while enjoying the quite delightful Italian food in this famously local and family-owned, 108 year old Bakersfield restaurant, delicatessen, and wine shop.

New Publication
"FROM WESTON TO CRESTON – A Compendium of Witnessed US Meteorite Falls – 1807 to 2016"

by **Frank Cressy**

The violent display of blazing light and explosive sounds ending with meteorites crashing to the ground is an unforgettable event to those who witness it firsthand. This book summarizes the fall histories of nearly 170 witnessed meteorite falls that have occurred in the United States since the first documented fall at Weston, Connecticut in 1807. It is written not only for the collector of these rare objects, but also for those interested in the history and the growth of the branch of science known as Meteoritics. The accounts of the fall phenomena and recoveries associated with these extraordinary events are the focus of the book. However, the book is more. The reader will learn about those individuals responsible for the growth of the science and their contributions, together with interesting facts and coincidences about these visitors from space; 257 pages with over 300 color photos plus maps, figures and illustrations.

Soft Cover books $36.00; for ordering, contact: fcressy@prodigy.net



Pacific Section Geologists Race for Pediatric Cancer

By: Becca Schempp

Every September thousands of athletes participate in the Nautica Malibu Triathlon, benefitting Children's Hospital Los Angeles (CHLA). The cause is near and dear to many local Pacific Section AAPG Geologists, specifically those that know Kevin and Lara Weberling who lost their son Hans to pediatric cancer. Hans was diagnosed with neuroblastoma at age 3 and bravely fought for 6 years.

Team Hans had an impressive roster of 35, including Pacific Section Geologists Kevin Weberling, Leonardo Pena, John Porter, Aaron and Sarah Hebeler, Cameron Campbell, Tracie Mosher, and Becca Schempp. Together they braved larger than expected waves and currents in the ½ mile swim, a not quite flat 17-mile bike ride, and 4-mile run. This year Team Hans raised more than $39,000, and has raised $87,000 over the last four years.

Team Hans is a part of Sophia's Buddies, a group of 10 teams honoring 11 angels and warriors. This year Sophia's Buddies raised $134,526. The fundraising efforts put Sophia's Buddies in 3rd place, out-fundraised by Disney and CHLA.

The triathlon was a great way to spend time with friends, coworkers, and give back to such an important cause. Athletes can participate as individuals or in a relay team of two or three. Team Hans is always open to welcoming more members. Race day is the third weekend in September. Go Team Hans!

8th Annual Pacific Section Student Chapter Leadership Summit

By:

Becca Schempp

This past weekend marked the 8th Annual Pacific Section Student Chapter Leadership Summit in Bakersfield, California. College students from across the Pacific Section are invited to attend the annual event. Most of the students are officers in their AAPG Student Chapter, but schools without Student Chapters are invited and encouraged to attend as well. Cole Heap is the new Pacific Section Student Liaison. He has been hard at work planning this year's summit.

The entire weekend was cost-free to the students. Their travel reimbursed, meals are provided and perhaps the largest saving and notable aspect is that we home-host the students. Local Bakersfield geologists open their homes to SLCS attendees. It allows the students to get to know a working geologist and hopefully foster a unique opportunity for mentorship.

The SCLS has grown quite a bit since the first year in 2010, when just a few local schools attended. Now out of state colleges University of Oregon, Portland State, and University of Alaska, Fairbanks are regular attendees. In the past, local industry professionals presented most of the information to the students. Yet, over the years as more Student Chapters got involved a shift happened. Now the students share their experiences with Imperial Barrel Competition, best practices for keeping their chapters going, finding and keeping members, and helping their members stay involved. It takes a lot of work to start a Student Chapter and a lot more work to keep the momentum going. Especially with internships, thesis work and writing. The information and "hacks" that the students can learn from each other is incredibly valuable. Collaboration is crucial.

They also got to ask a panel of local industry professionals questions about school (undergraduate, graduate, and post graduate), getting hired, and more. They heard what it's like being a petroleum geologist, how it's changed over the last few years and what's expected in the future.

A running theme was "how small the oil patch is." You never know who you're going to be working with or for, so be the best you. I am currently the PSAAPG Foundation Treasurer, every Spring it is with great joy that I write ~$20,000 worth of scholarships to our budding future geologists. Many of the names are familiar to me, sometimes by both face and name. It's these names of students that step up to lead AAPG Student Chapters. It's these names that attend our West Coast Expo, and perhaps others. It's these names that compete in the annual IBA Competition. It's these names that are selected as college interns for our companies. And finally, they are the names that become our colleagues when they finish their degrees. These hardworking, willing, determined students are taking advantage of all that Pacific Section has to offer.

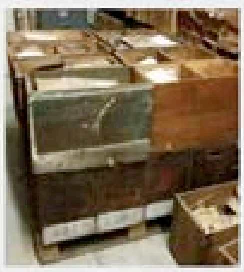
The Student Chapter Leadership Summit is one of my favorite events of the year. It's always so impressive to meet the next group of leaders. A big thank you to everyone that helps make the Student Chapter Leadership Summit a success year after year.

California Well Sample Repository

Our 60+ Volunteers

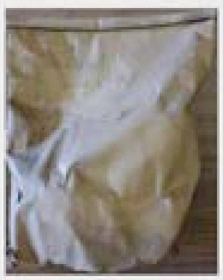
Our Volunteers curate material from Superior Oil Company's collection from the early 1930's.

Step 1



Wooden Crates with Samples

Step 2

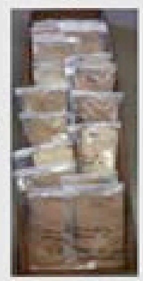


Samples in Paper Bags from 1920's

Step 3

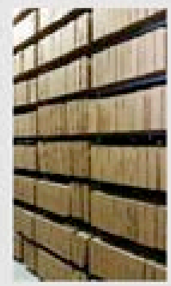
Samples Transferred into Plastic Bags

Step 4



Plastic Bags Placed into Boxes

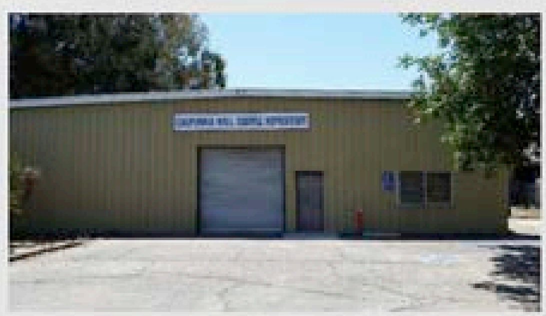
Step 5



Boxes Placed on Shelf

Dr. Victor Church Memorial

The only facility in California providing permanent storage and public use of cores, sidewall samples, drill cuttings, outcrop samples, microfaunal slides, foundation borings, and mineral suites.



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Alaska Geological Society

November 20th

Speaker: John Lyons, USGS, Alaska Volcano Observatory, Anchorage, AK

Talk: Monitoring and studying active volcanoes with low frequency sound in Alaska, Hawaii, and beyond

Coast Geological Society

November 20th

Speaker: Jim O'Tousa

Talk: Geologist Input Key to Prepare, Respond, and Recover from Debris Flow Events

L.A. Basin Geological Society

Talks have resumed this September, 2018.

Northern California Geological Society

November 28th

Speaker: Dr. Stephen Self, University of California, Berkeley

Talk: Anticipating future Volcanic Explosivity Index (VEI) 7 eruptions and their chilling impacts

Northwest Energy Association

November

Tentative Talk: Representative of the City of Portland emergency preparedness group to give an update on Portland's preparation for a Cascadia mega-earthquake event

Sacramento Petroleum Association

Talks have resumed this September, 2018.

San Joaquin Geological Society

Talks have resumed this October, 2018.

Alaska Geological Society

www.alaskageology.org

P. O . Box 101288
Anchorage, AK 99510

Contact: Keith Torrance
ktorrance@gci.net

Geology meetings/talks are held monthly September through May, usually on the third Thursday of the month, at the BP Energy Center (1014 Energy Court) from 11:30 am to 1:00 pm. Open To The Public. No Charge to Attend.

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Treasurer:	Holly Fair	holly.fair@alaska.gov
Past-President:	Larry Smith	Ljsmithak@gmail.com

Coast Geological Society

www.coastgeologicalsociety.org

P. O. Box 3055
Ventura, CA 93006

Contact: Eric White
805-628-2312

Dinner meetings are held monthly September through May, on the third Tuesday of the month, at Poinsettia Pavilion, 3451 Foothill Road in Ventura. Social hour starts at 6:00 p.m., dinner is served at 7:00 p.m., and the talk starts at 8:00 p.m.
The cost of dinner with reservations is $20 (members), $25 (non-members), or $10 (students and K-12 teachers).
For reservations, please email Shelby Fredrickson (secretary@coastgeologicalsociety.org), and should be made by 4:00 p.m. on the Friday before the meeting.

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Los Angeles Basin Geological Society

www.labgs.org

Contact: Bert Vogler
949-585-3103

Luncheon meetings are held monthly September and October; and January through June, usually on the fourth Thursday of the month, at The Grand at Willow Street Conference Centre (4101 E. Willow Street) in Long Beach. Lunch is served at 11:30 a.m., and the talk starts at 12:15 p.m. The cost is $25 (with reservations), $30 (without reservations), $20 for retired members, and $5 for students. "Reservations can be made online at www.labgs.org or by contacting Maia Davis at 530-559-1404 or maiac.davis@gmail.com. Reservations are best made prior to Tuesday before the meeting.

President:	Bert Vogler	hvogler@kleinfelder.com
Vice President	Nate Busch	nbusch@eecenvironmental.com
Treasurer:	Nicky White	nwhite@geomechanicstech.com
Secretary:	Maia Davis	maiac.davis@gmail.com
Scholarships:	Karla Tucker	ktkr2@aol.com
Webmaster	Ivan Aburto	Ivan.aburto@crc.com

Northern California Geological Society

www.ncgeolsoc.org

803 Orion #2
Hercules, CA 94547-1938

Contact: Barbara Matz
barbara.matz@aptim.com

Evening meetings are held monthly September through May, usually on the last Wednesday of the month, at the Masonic Center (9 Altarinda Road) in Orinda. Social hour starts at 6:30 p.m., and the talk starts at 7:00 p.m. (no dinner).
For reservations, contact Dan Day at danday94@pacbell.net before the meeting.
Cost is $5 per regular member; $1 per student member; and $1 per K-12 teachers.

(Continued on next page)

NCGS Officers

President:	Greg Bartow	gregbartow@yahoo.com
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Past President:	Will Schweller	willschweller@yahoo.com
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Northwest Energy Association

www.nwenergy.us

P. O. Box 6679
Portland, OR 97228

Contact:
Jim Jackson or John Armentrout

Luncheon meetings are held monthly September through May, on the third Thursday of the month, at the Multnomah Athletic Club (1849 SW. Salmon Street) in Portland, Oregon. Meeting time is at 11:45 AM to 1:00 PM (speaker about 12:15 PM). The cost is $25 for members and $30 for non-members. For information or reservations email NWEnergyAssociation@gmail.com, or our Postal Box: Northwest Energy Association, P.O. Box 6679, Portland, Oregon 97228-6679.

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Sacramento Petroleum Association

P. O. Box 1844
Folsom, CA 95630

Contact: Pam Ceccarelli
916-439-0400

Luncheon meetings held monthly January through November, on the third Wednesday of the month. Location: Club Pheasant Restaurant in West Sacramento. The meetings start at noon. The cost is $16 - $20. For information or reservations, contact Pam Ceccarelli.

President:	Jerry Reedy	JWR5532@aol.com
Vice-President:	Scott Hector	Scott.Hector@gmail.com
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San Joaquin Geological Society

www.sanjoaquingeologicalsociety.org

P. O. Box 1056
Bakersfield, CA 93302

Contact: Lindsey Thompson
lthompson@envirotechteam.com

We have dinner meetings on the second Tuesday of the month, October through June, at the American Legion Hall (Post 26) at 2020 H Street, Bakersfield, CA 93301. There is an icebreaker at 6:00 p.m., dinner at 7:00 p.m., and a talk at 8:00 p.m. Dinner is $25 for members with reservations and $30.00 for nonmembers and members without reservations. Students may attend for free.

President:	Cameron Campbell	cameron.campbell@conservation.ca.gov
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