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Title: Testing the Extensional Detachment Paradigm: Scientific Drilling in the Sevier Desert Basin (Basin and Range Province, Western United States)

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Location: Utah

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Permission to post abstract on ICDP Web site: ☒ Yes ☐ No

Abstract: *(400 words or less)*

Low-angle normal faults or detachments are widely regarded as playing an important role in crustal extension and the development of passive continental margins. However, no consensus exists on how to resolve the mechanical paradox implied by such faults or on the general absence of evidence for seismicity. The purpose of proposed drilling in the Sevier Desert basin in the western United States is to test the extensional detachment paradigm through coring, downhole logging, biostratigraphic, isotopic and fission-track dating, magnetostratigraphy, and in situ measurement of pore pressure, permeability, fluid chemistry, temperature, and stress orientation/magnitude at an example for which evidence of large normal-sense slip on a detachment of particularly low dip (11°) is widely regarded as among the most convincing, and for which a case can be made for contemporary displacement. While no seismicity has been documented on the Sevier Desert detachment, its scale is consistent with earthquake magnitudes as large as M 7. Given a location ~150 km southwest of Salt Lake City, it rivals the more active but segmented Wasatch fault as a seismic hazard.

We propose to hold an international workshop on “Scientific Drilling in the Sevier Desert Basin” in June or July, 2008. The purpose of the meeting is to flesh out objectives, strategies and operational details, with input from a much broader constituency of interested scientists than is represented by the PIs, and to develop a consensus on the location of a drill site. This will be informed by an already comprehensive evaluation of existing subsurface data, and by the need to balance optimal science against cost. The most important product of the workshop will be a full drilling proposal to be submitted to ICDP in January, 2009.

Candidate drill sites are located east of a line along which the interpreted detachment passes from the contact between Paleozoic carbonate rocks and Cenozoic basin fill into deformed Neoproterozoic and Paleozoic rocks of the Mesozoic orogen on which the basin is superimposed. A compelling case can be made for a hole as deep as 4,000 m, at which depth fault rocks (both ductile and brittle) are most likely to be preserved. In interpreting basin evolution (and the history of displacement along the detachment), it will also be useful to sample as complete a stratigraphic record as possible. Compromise sites can be considered, but a borehole shallower than ~2,000 m risks not achieving important geological objectives.

Scientific Objectives: (*250 words or less*)

Geological studies in the proposed borehole are aimed at elucidating the character of the Paleozoic-Cenozoic contact and the long-term evolution of the basin – together constituting a new critical test of the detachment hypothesis. In situ measurements are aimed at determining the conditions under which displacement may have taken place, as recently as the Holocene, consistent with the generally accepted interpretation of the geology. Specific issues to be addressed include the following:

• Evidence for ductile and/or brittle deformation vs an unconformable contact, recognizing that fault rocks may have been partially removed by erosion prior to burial, and that an originally unconformable contact may have been involved in faulting.

• The history of sediment accumulation, and how the timing of basin development relates to exhumation of the hypothesized footwall of the detachment. A full suite of downhole logs (especially acoustic logging) will allow confident correlation with seismic reflection data.

• In situ physical conditions along the detachment zone, including pore pressure, fracture permeability, fluid chemistry, temperature, the orientation of stress axes and the magnitude of differential stress. Employing methods developed and refined for the KTB and SAFOD drilling projects, particularly hydraulic fracturing tests and analysis of tensile and compressional (breakout) failures of the wellbore wall, it will be possible to estimate the complete stress tensor at depth along the detachment zone.

Summary of Support Requested from ICDP

Requested ICDP funds: *(in US$)*	$46,000	Estimated Total Project Budget *(ICDP funds plus other sources)*:	
Planned Start:	July 15, 2007	Estimated Duration in Month *(On-site operations only)*:	

Requested Operational Support:	Drill Engineering *(Please contact ICDPs Operational Support Group if required)*	
	Downhole Logging *(Please contact ICDPs OSG if required)*	
	Field Lab Equipment *(Please contact ICDPs OSG if required)*	
	Training Course *(Please contact ICDPs OSG if required)*	

Details such as a Budget Plan, Management Plan, and Drilling Plan to be provided as attachment to the Proposal. OSG contact: U. Harms (ulrich@gfz-potsdam.de), Phone: +49 331 288 1085

Workshop Proposal to the International Continental Scientific Drilling Program (ICDP)

Testing the Extensional Detachment Paradigm: Scientific Drilling in the Sevier Desert Basin

(Basin and Range Province, Western United States)

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INTRODUCTION

The manner in which continents extend and eventually break apart to form ocean basins is a first-order issue in tectonics and geodynamics (Karner et al., 2004; and in press). Of particular interest is the role that may be played by low-angle normal faults or detachments (e.g., Wernicke, 1981, 1985; Lister and Davis, 1989; Froitzheim and Eberli, 1990; Lister et al., 1991; Reston et al., 1996; Rietbrock et al., 1996; Abers et al., 1997; Driscoll and Karner 1998; Hodges et al., 1998; Osmundsen et al. 1998; Taylor et al., 1999; Boncio et al., 2000; Manatschal et al., 2001, and in press; Axen, 2004; Canales et al., 2004). Individual structures are interpreted to account for up to tens of kilometers of crustal extension, and for rapid exhumation of rocks from mid- to lower crustal and even subcrustal depths (e.g., Allmendinger et al., 1983; Axen et al., 1990; Baldwin et al., 1993, 2004; Holm et al., 1992; John and Foster, 1993; Jolivet et al., 1996; Snow and Wernicke, 2000; Livaccari and Geissman, 2001; Manatschal et al., 2001, and in press; Canales et al., 2004; DeCelles and Coogan, 2006). They provide a mechanism for spatial partitioning of extensional strain, with implications for the stratigraphic and thermal evolution of associated sedimentary basins and for the exploitation of hydrocarbon resources in extensional and passive-margin settings (Kusznir et al., 1987; Lister et al., 1991; Friedmann and Burbank, 1995; Karner and Driscoll, 1999). By virtue of their inferred large scale, still-active detachments may represent a significant seismic hazard even if recurrence intervals are correspondingly long (Wernicke, 1995).

In spite of the evident success of the extensional detachment paradigm in integrating and accounting for diverse geological observations, no consensus exists on two important aspects of fault mechanics. First, brittlely deforming low-angle normal faults represent an extreme case of the weak fault paradox, involving displacement with resolved shear stresses substantially smaller than those expected on the basis of laboratory observation and Coulomb rheology (Axen, 1992, 2004; Axen and Selverstone, 1994; Sibson, 1985; Manatschal, 1999; Westaway, 1999; Collettini and Sibson, 2001; Floyd et al., 2001; Hayman et al., 2003; Collettini and Holdsworth, 2004; Scholz and Hanks, 2004). At issue is whether the maximum principal stress is necessarily vertical (Faulkner et al., 2006), and whether rocks are necessarily coulombic when faults slip. Second, although earthquakes have been interpreted on low-angle normal faults (e.g., Abers, 1991; Wernicke, 1995; Rietbrock et al. 1996; Abers et al. 1997; Boncio et al., 2000; Collettini and Barchi 2002), the evidence is equivocal, and the general absence of evidence for seismicity on such structures has yet to be explained satisfactorily (Jackson 1987; Jackson and White, 1989). If geological relationships are correctly interpreted, therefore, the potential exists for low-angle normal faults to provide new insight into fault mechanics.

The challenge for geologists and geophysicists is to demonstrate that a now-gently dipping normal fault was active at a low angle or that observed seismicity relates unambiguously to such a fault. Originally high-angle faults are progressively tilted to lower inclinations during extension. This is observed where extension is accommodated by suites of tilted blocks like books upon a shelf (Proffett, 1977; Miller et al., 1983; Jackson and White, 1989) and perhaps by passage of the footwall, continuously or discontinuously, through a "rolling hinge" from a steeply inclined active fault to a more gently inclined, exhumed and inactive portion of the same structure (Buck, 1988; Wernicke and Axen, 1988; Weissel and Karner, 1989; Miller, 1991; Holm et al., 1992; Axen and Bartley, 1997; Lavier et al., 1999; Gessner et al., 2001; Lavier and Manatschal, 2006).

Among evidence cited in favor of normal-sense slip along an originally low-angle fault are cut-off angles against layered sediments and sedimentary rocks, the geometric relationship between high-angle faults and detachments, footwall thermochronology and barometry, paleomagnetically determined orientation, and the apparent youth of deformation (e.g., Allmendinger et al., 1983; Von Tish et al., 1985; Lister and Davis, 1989; Axen et al., 1990; Scott and Lister, 1992; John and Foster, 1993; Livaccari et al., 1993; Axen and Selverstone, 1994; Brady et al., 2000; Livaccari and Geissman, 2001; Hayman et al., 2003; Axen, 2004; Niemi et al., 2004).

Taken together, this evidence is regarded by many as compelling (Wernicke, 1995; Axen, 1999, 2004). Yet unresolved questions remain for virtually every published example: e.g., the temporal and kinematic relationships among mylonites, brittle detachments and other faults (Lister and Davis, 1989; Proffett, 2002; Miller and Pavlis, 2005), the possible role of diapiric ascent versus low-angle normal faulting in the rapid exhumation of some metamorphic rocks (Fayon et al., 2004), the possible contribution of rolling hinges and whether, more generally, detachment dips of < ~20-30° (Sibson, 1985; Collettini and Sibson, 2001) are necessarily implied by available thermochronology (Axen and Bartley, 1997; John et al., 2004); the need to distinguish crustally rooted normal faults from gently inclined detachments associated with surficial slide blocks, particularly in areas of pronounced topographic relief (Boyer and Allison, 1987; Hauge, 1993; Anders et al., 2006); and even whether a fault is present (Anders and Christie-Blick, 1994; Anders et al., 2001; Wills et al., 2005).

As G.J. Axen states in his 2004 review (p. 50), "Even one compelling example of a primary LANF [low-angle normal fault] or of LANF slip is sufficient to prove that they may form and slip at low dip, respectively." The purpose of the proposed drilling in the Sevier Desert basin is to test the extensional detachment paradigm through coring, downhole logging, biostratigraphic, isotopic and fission-track dating, magnetostratigraphy, and *in situ* measurement of pore pressure, permeability, fluid chemistry, temperature, and stress at an example for which evidence of large normal-sense slip on a detachment of particularly low dip (11°) is widely regarded as among the most convincing, and for which a case can be made for contemporary displacement (Wernicke, 1995; Niemi et al., 2004).

GEOLOGICAL CONTEXT OF SEVIER DESERT BASIN

The Sevier Desert basin is located in west-central Utah, in the eastern part of the Basin and Range Province – a broad region of Oligocene and younger extension in the western United States and northern Mexico, bounded on the east by the Colorado Plateau, and on the west by the diffuse transform plate boundary of the San Andreas system (Figs. 1 and 2; Wernicke, 1992; Wills et al., 2005). Extension in the Sevier Desert region was superimposed on a late Jurassic to early Tertiary orogen (the Sevier orogenic belt; Armstrong, 1968; Allmendinger, 1992; DeCelles and Coogan, 2006), and on the inner hinged or continentward parts of a west-facing (deepening) Neoproterozoic to mid-Devonian passive continental margin and composite younger Paleozoic to Triassic foreland (Stewart, 1972; Bond et al., 1985; Burchfiel et al., 1992; Smith et al., 1993). Pre-orogenic development is represented by < 7 km of Neoproterozoic to Lower Cambrian mostly clastic sedimentary rocks, and by < 9 km of mid-Cambrian to Triassic mostly carbonate rocks (Christie-Blick, 1982, 1997; Hintze, 1993; Hintze and Davis, 1993; Link et al., 1993; DeCelles and Coogan, 2006) – rocks that now underlie the basin and are to be found in outcrop in surrounding ranges.

The basin is strongly asymmetric towards the west, with as much as 4 km of predominantly fine-grained siliciclastic and volcaniclastic lacustrine fill, and more than 1 km of basal relief in a north-south direction (Figs. 3-5; Wills et al., 2005). Two of nine wells studied by Wills et al. intersect basalt flows

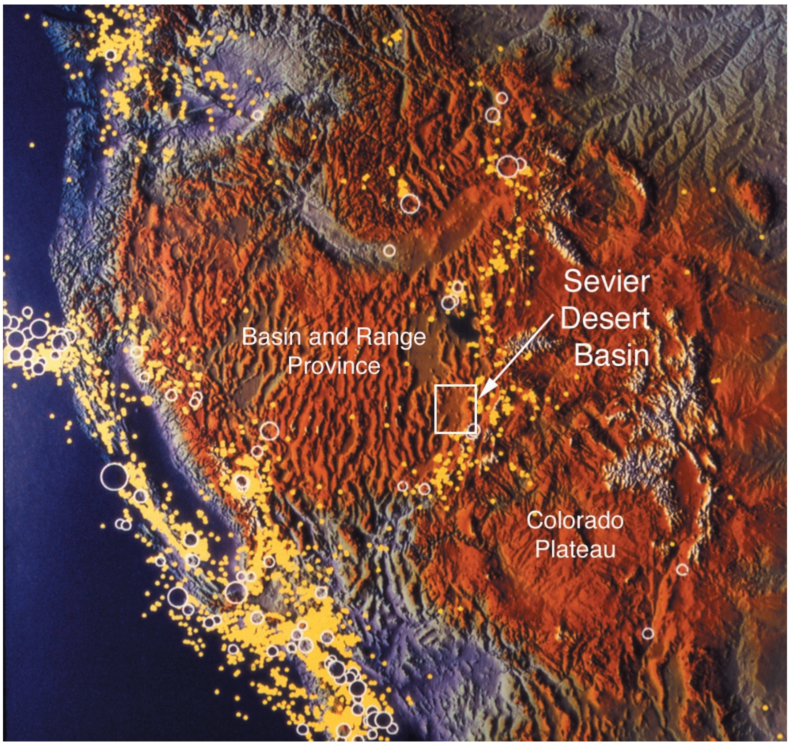

Figure 1. Location of the Sevier Desert in western U.S. Dots and circles are earthquakes. The north trending band of earthquakes adjacent to the Sevier Desert marks the eastern boundary of the Basin and Range. The intense seismicity to the west of the Basin and Range results from the San Andreas fault system. The western boundary of the Basin and Range is marked by the less intense seismicity associated with the Walker-Lane fault system.

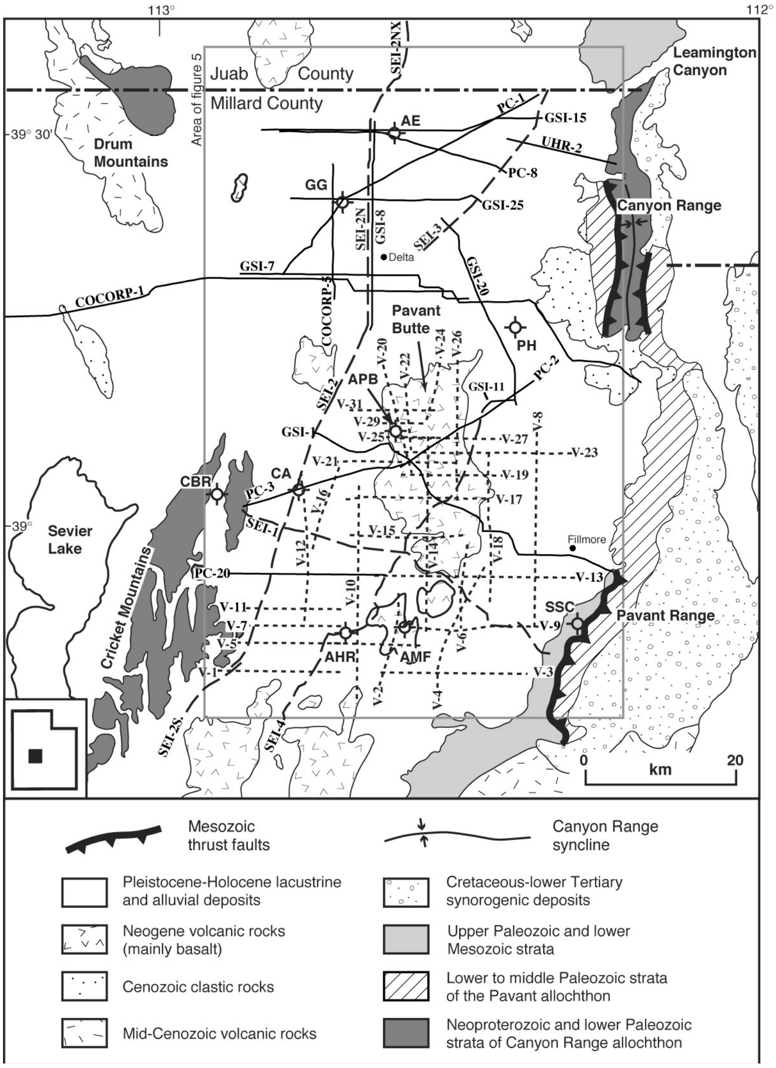

Figure 2. Generalized map of Sevier Desert basin in west-central Utah showing locations of seismic profiles and wells (see figure 1 for location map). Solid, dashed and dotted lines correspond with different seismic datasets. COCORP Utah Line 1 is shown in figure 3. Wells: AE, Argonaut Energy Federal; AHR, ARCO Hole-in-Rock; AMF, ARCO Meadow Federal; APB, ARCO Pavant Butte; CA, Cominco American Federal; CBR, Chevron Black Rock; GG, Gulf Gronning; PH, Placid Henley; SSC, Shell Sunset Canyon. Thrust faults are Canyon Range thrust in Canyon Range, and the structurally lower Pavant thrust in the Pavant Range (teeth on upper plate). Gray box shows area of figure 5 (modified from Wills et al., 2005).

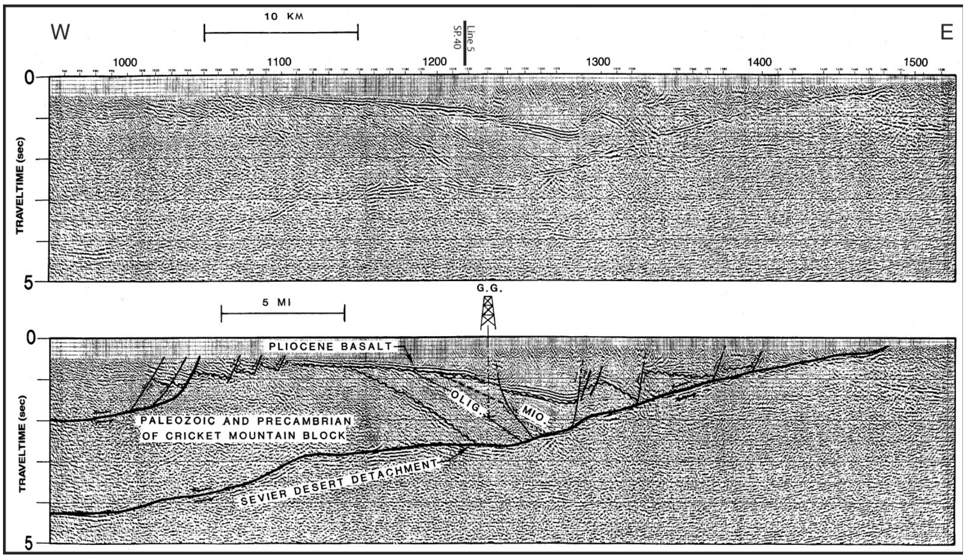

Figure 3. Part of seismic reflection profile COCORP Utah Line 1, with interpretation of Sevier Desert detachment from Von Tish et al. (1985). The dominant reflector, thought to be the Sevier Desert detachment, can be traced to a depth of 15 km at an average dip of about 11°. See figures 2 and 5 for map location of the reflection line.

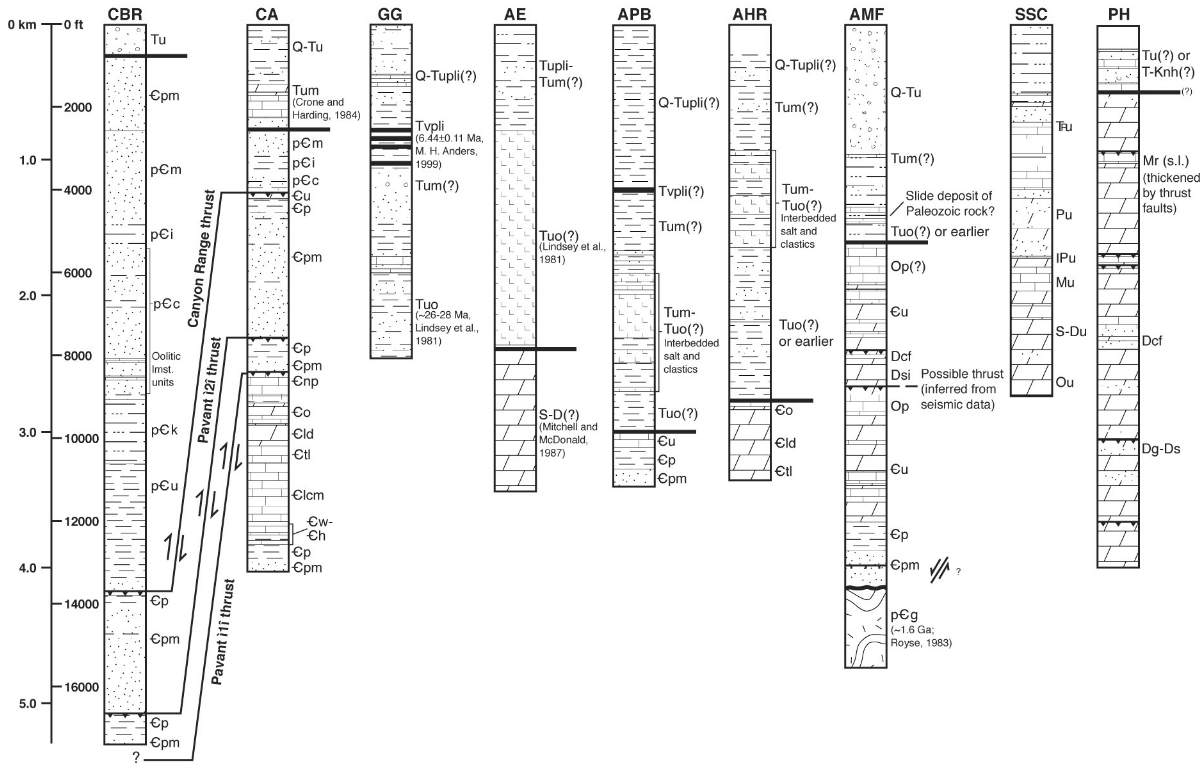

Figure 4. Summary of stratigraphy of the industry wells drilled in the Sevier Desert basin with dark lines indicating fault contacts. Well locations shown on Fig. 2 (modified from Wills et al., 2005).

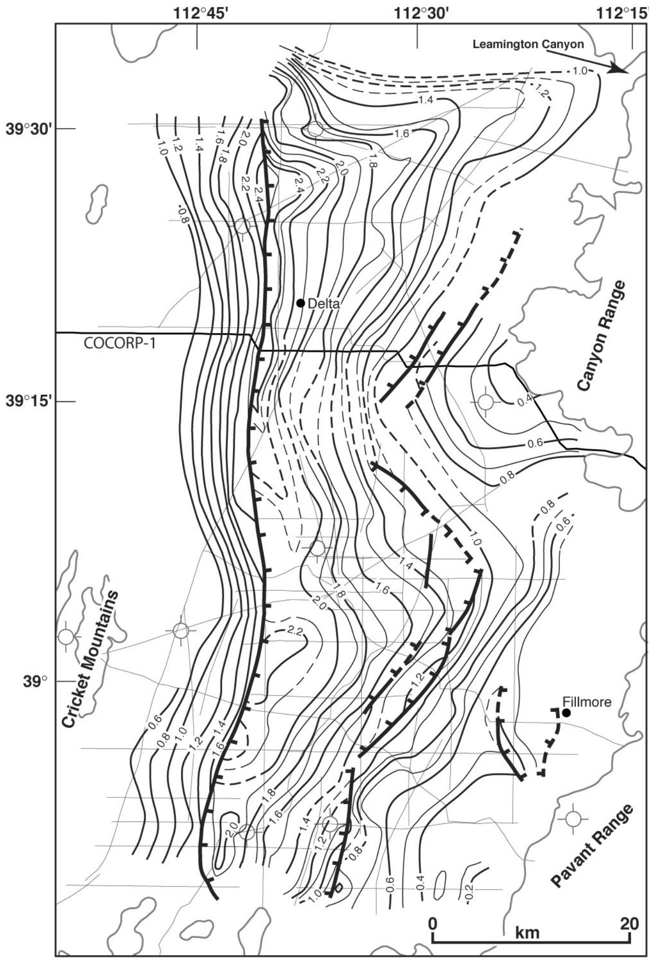

Figure 5. Structural contour map of the base of Cenozoic rocks in the Sevier Desert. Contours are in two-way-travel time based on seismic reflection lines and industry wells as shown in figure 2. The area encompassed in this figure corresponds to the boxed area labeled "Figure 5" in figure 2 (modified from Wills et al., 2005).

(GG and APB in Figs. 2 and 4); four wells (GG, APB, AHR and AE in Figs. 2 and 4) penetrate intervals of evaporites, including 1,571 m (5152 ft) of halite in Argonaut Energy Federal No. 1 (AE). Age data are limited. Zircon and apatite fission-track dating in the most intensively studied hole (Gulf Gronning No. 1; GG in Figs. 2 and 4) suggests that tuffaceous sandstone 350 m above the bottom of the hole is of late Oligocene age (28-26 Ma; Lindsey et al., 1981), an estimate that is consistent with available pollen data. As much as 2 km of sediment underlie the dated level in the deepest part of the basin (Mitchell and McDonald, 1987; Wills et al., 2005).

SEVIER DESERT DETACHMENT

Interpretations of a detachment beneath the Sevier Desert (Figs. 2 and 3) are based primarily on 1970s vintage petroleum industry seismic reflection data (McDonald, 1976; Wernicke, 1981; Wernicke and Burchfiel, 1982; Smith and Bruhn, 1984; Mitchell and McDonald, 1987; Planke and Smith, 1991; Coogan and DeCelles, 1996, 1998) and seismic profiles acquired by the Consortium for Continental Reflection Profiling (COCORP; Allmendinger et al., 1983, 1987; Von Tish et al., 1985; Allmendinger and Royse, 1995). The 11° westward dip of the hypothesized detachment, its lateral continuity over 7,000 km^2 beneath the basin and (downdip) within deformed Neoproterozoic and Paleozoic rocks of the Cricket Mountains block (Fig. 2), the inferred offset of Cretaceous structures by as much as 47 km (DeCelles and Coogan, 2006), the presence of a prominent culmination in crystalline basement rocks beneath the basin, the downward termination of high-angle normal faults at the base of the basin fill, and the involvement of sediments as young as Holocene provide seemingly unassailable evidence for large normal offset on a fault that could never have been appreciably more steeply inclined than it is today, and is arguably still active (Wernicke, 1981, 1995; Niemi et al., 2004; Wills et al., 2005). Interpreted stratigraphic growth (eastward tilting) along the western margin of the basin is consistent with displacement on the detachment after 28-26 Ma (based on the Gulf Gronning data; McDonald, 1976; Allmendinger et al., 1983; Von Tish et al., 1985; Coogan and DeCelles, 1996, 1998; Stockli et al., 2001). Fission track ages from footwall rocks in the Canyon Range (19-15 Ma from apatite; Fig. 2) and ARCO Meadow Federal well (13.0 ± 1.0 Ma to 10.8 ± 0.9 Ma from zircon; AMF in Fig. 2), and from hanging-wall rocks in Cominco American Federal well (8.5 ± 2.2 Ma from apatite; CA in Fig. 2) are attributed to mid- to late Miocene displacement and tectonic exhumation along the hypothesized detachment (Allmendinger and Royse, 1995; Stockli et al., 2001). Brittle deformation along the west flank of the Canyon Range is interpreted as an updip outcrop expression of hypothesized detachment (Otton, 1995, 1996).

This generally accepted interpretation of a detachment has been questioned primarily though not exclusively by a group at Columbia University, based upon the absence of evidence in well cuttings and cores for either brittle deformation (above) or ductile deformation (below), and details of the subsurface stratigraphic and structural interpretation that are regarded as at odds with key elements of published palinspastic reconstructions (Anders and Christie-Blick, 1994; Hamilton, 1994; Anders et al., 2001; Hintze and Davis, 2003; Wills et al., 2005; Christie-Blick et al., in press; Christie-Blick and Anders, in press). According to these authors, deformation in outcrop in the Canyon Range (Fig. 2) relates not to a crustally rooted detachment, but to mapped Mesozoic fold hinges and faults, and to slide blocks that are demonstrably surficial (Hamilton, 1994; Wills and Anders, 1996, 1999). The apparent continuity of a prominent multicyclic seismic reflection beneath the basin to within deformed Neoproterozoic and Paleozoic rocks of the Cricket Mountains block to the west is restricted to the northern part of the basin owing to fortuitous alignment of a basin-flooring unconformity with a Cretaceous thrust fault. The same fault and a structurally higher thrust are interpreted as erosionally truncated at the western margin of the southern Sevier Desert basin, and not offset by a detachment in the manner assumed by those inferring large extension. The culmination in crystalline rocks beneath the basin is attributed to a ramp in a hypothesized intrabasement thrust fault (Anders et al., 1995). Inferred post-late Oligocene growth is based upon a mistaken correlation between seismic reflection data and the Gulf Gronning well (GG in Fig. 2; Anders et al., 1995, 1998; Wills et al., 2005). The supposedly Oligocene tilted strata imaged in COCORP Utah Line 1 (Olig. in Fig. 3) are reinterpreted as Paleozoic and Neoproterozoic. The basin fill is largely subhorizontal at all stratigraphic levels, and consistently onlaps the Cricket Mountains block to the west. Stratigraphic growth and downward-terminating normal faults are spatially and temporally localized in areas of intrabasinal salt tectonics. Fission track ages of 19 Ma and younger are viewed as too young to explain the development of a supradetachment basin at least as early as the Oligocene (Anders et al., 1995; Wills and Anders, 1999; Anders et al., 2001; Wills et al., 2005).

This alternative interpretation of the Paleozoic-Cenozoic contact as an unconformity rather than a detachment has not been generally accepted. It is argued that deformation along detachment faults is commonly restricted, and easily missed in the two wells that were sampled in this case (Allmendinger and Royse, 1995; DeCelles and Coogan, 2006). Microcrack data were obtained entirely from cuttings of basin fill. Caving of the borehole wall leads to uncertainty about the precise stratigraphic level of samples. The closest core of Paleozoic carbonate rock was from 12.8 m below the contact. Exhumation of the detachment would in any case have made it possible to remove critical footwall evidence prior to later sedimentary onlap, particularly at updip locations. The incomplete coverage and uneven quality of available seismic reflection data leave plenty of room for discussion about interpretive details, including the possibility that deformation was distributed across several closely spaced faults (Allmendinger and Royse, 1995; Coogan and DeCelles, 1998). Displacement along the detachment may have been overestimated. The age of the basin is not well constrained by available well data, and better interpreted from the timing of footwall exhumation (Stockli et al., 2001). A major exposed detachment fault (the Cave Canyon detachment) projects beneath the Sevier Desert basin along its southern flank (Coleman and Walker, 1994; Coleman et al., 1997; Niemi et al., 2004). Thus despite significant skepticism and attendant critical testing of the detachment hypothesis, the strong consensus among the majority of scientists working on the problem is that the hypothesis remains the best explanation for the basin itself, and is consistent with independent evidence for large-scale extension in the Basin and Range Province and for numerous geometrically analogous detachment systems (Wernicke, 1992, 1995; Niemi et al., 2004; DeCelles and Coogan, 2006).

SCIENTIFIC OBJECTIVES

We propose to test the extensional detachment paradigm through a combination of coring, downhole logging, biostratigraphic, isotopic and fission-track dating, magnetostratigraphy, and *in situ* measurement of pore pressure, permeability, fluid chemistry, temperature, and stress in a 2,000- to 4,000-m-deep borehole in the Sevier Desert basin. The geological studies are aimed at elucidating the character of the Paleozoic-Cenozoic contact and the long-term evolution of the basin – together constituting a new critical test of the detachment hypothesis. *In situ* measurements are aimed at determining the conditions under which displacement may have taken place, as recently as the Holocene, consistent with the generally accepted interpretation of the geology. Specific issues to be addressed include the following:

- Evidence for ductile and/or brittle deformation vs an unconformable contact, recognizing that fault rocks may have been partially removed by erosion prior to burial, and that an originally unconformable contact may have been involved in faulting.
- The history of sediment accumulation, and how the timing of basin development relates to exhumation of the hypothesized footwall of the detachment. A full suite of downhole logs (especially acoustic logging) will allow confident correlation with seismic reflection data.
- *In situ* physical conditions along the detachment zone, including pore pressure, fracture permeability, fluid chemistry, temperature, the orientation of stress axes and the magnitude of differential stress. Employing methods developed and refined for the KTB[1] and SAFOD[2] drilling projects, particularly hydraulic fracturing tests and analysis of tensile and compressional (breakout) failures of the wellbore wall, it will be possible to estimate the complete stress tensor at depth along the detachment zone.

The proposed drilling relates to two ICDP research themes: the physical and chemical processes responsible for earthquakes; and the origin of sedimentary basins. It complements efforts to understand the genesis of earthquakes in strike-slip and subduction zone settings, as well as in extensional settings such as the Gulf of Corinth. Supradetachment basins constitute a potentially important class of sedimentary basin that is not yet well understood (Friedmann and Burbank, 1995).

JUSTIFICATION FOR DRILLING THE SEVIER DESERT BASIN

The Sevier Desert basin represents a world class scientific drilling opportunity, with the potential for establishing beyond any doubt that normal-sense slip can occur along a brittle low-angle fault, and for determining the conditions under which that may take place. The interpreted detachment is regionally well defined at the contact between Paleozoic carbonate rocks and Cenozoic basin fill at a depth range of ~0-4 km (Allmendinger et al., 1983; Von Tish et al., 1985; Wills et al., 2005), roots into the crust west of the Sevier Desert, is of large estimated offset (< 47 km; DeCelles and Coogan, 2006), cannot have been active at a dip much greater than its present 11°, and may be associated with contemporary extension (Anderson and Miller, 1979; Christenson et al., 1987; Oviatt, 1989; Niemi et al., 2004). A western basin-bounding fault system coincides today with a 30-km-long zone of both east- and west-down Holocene scarps (the Clear Lake scarps; CL in Fig. 6; Oviatt, 1989). At depth, the fault offsets a 6.44 Ma basalt (Wills et al., 2005) ~ 1,000 m. The most prominent of the Clear Lake scarps has a west-side down net vertical tectonic displacement of 3 m that is probably entirely post-Bonneville (< 17 ka) and may be entirely Holocene (Oviatt, 1989), suggesting a maximum vertical slip rate of ~0.3 mm yr^{-1}. Niemi et al. (2004) infer that the faults terminate against the detachment, which therefore may have slipped most recently in the Holocene. While no seismicity has been documented on the detachment (SDD in Fig. 6), its scale is consistent with earthquake magnitudes as large as M 7 (Wernicke, 1995). Given a location ~150 km southwest of Salt Lake City, it rivals the more active but segmented Wasatch fault (WPS, WNS, WLS and WFS in Fig. 6) as a seismic hazard. Extension determined geodetically as part of the BARGEN experiment (Basin and Range Geodetic Network; Wernicke et al., 1998, 2000) is

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[1] Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland or German Continental Deep Drilling Program.
[2] San Andreas Fault Observatory at Depth.

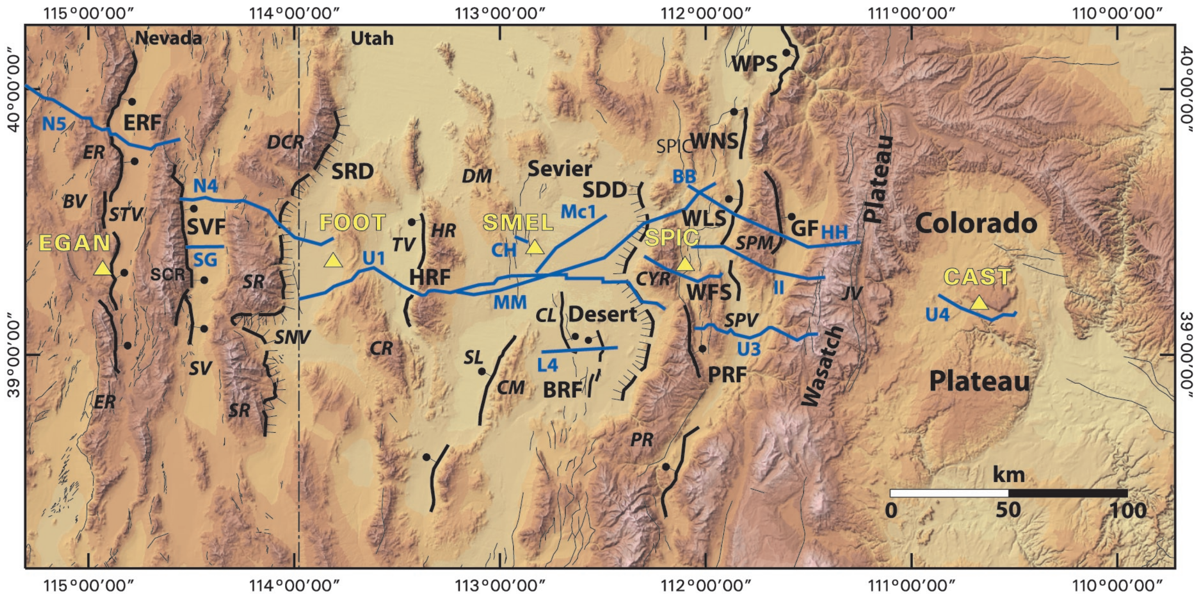

Figure 6. Shaded relief map showing location of Global Positioning System (GPS) sites (yellow triangles), seismic reflection profiles (blue lines), and surface traces of high-angle (bold line with ball on hanging wall) and low-angle (hachures on hanging wall) normal faults (from Niemi et al., 2004; Basin and Range Geodetic Network, or BARGEN). SDD is the presumed surface projection of the Sevier Desert detachment.

focused on the Wasatch fault, but from the west side of the Canyon Range (site SPIC in Fig. 6) to the Confusion Range (site FOOT in Fig. 6), there is still 0.7 ± 0.1 mm yr^{-1} of differential west velocity over the past 5 years. This is inferred to be accommodated primarily by displacement on the House Range fault and Sevier Desert detachment (HRF and SDD in Fig. 6). About 0.35 mm yr^{-1} is typical for Basin and Range faults.

The Sevier Desert detachment figured prominently in the development of ideas about low-angle normal faulting (Wernicke, 1981, 1985), as an example not closely associated with metamorphic core complexes (Crittenden et al., 1980), and because it was recognized early, in the course of petroleum exploration (McDonald, 1976). Its impact on thinking in the academic world was subsequently reinforced by publication of the well known COCORP seismic reflection profile (Allmendinger et al., 1983, 1987; Von Tish et al., 1985). The seismic reflection and exploration well data have been examined and re-examined in the course of numerous studies (Lindsey et al., 1981; Smith and Bruhn, 1984; Mitchell and McDonald, 1987; Planke and Smith, 1991; Royse, 1993; DeCelles et al., 1995; Coogan and DeCelles, 1996; Wills et al., 2005; DeCelles and Coogan, 2006). Available outcrop where the detachment may project to the surface on the west side of the Canyon Range (Fig. 2) has also been studied in detail (Hintze and Davis, 1993; Otton, 1995; Mitra and Sussman, 1997; Wills and Anders, 1999). Stockli et al. (2001) undertook a comprehensive fission track study of the Canyon Range. Together, these studies provide an excellent framework for scientific drilling.

Drilling is now needed specifically to make *in situ* measurements at depth, to sample fault rocks at a down-dip site where strain ought to have been large though perhaps localized in both ductile and brittle fields, and to establish more clearly the relationship between basin development and displacement along the interpreted detachment. Existing industry data are not adequate for this purpose: few cores were taken; none of the wells penetrating the detachment level are able to resolve details of the contact; downhole logs are incomplete, and up to several decades old. However, the wells do provide vital information about the drilling environment that is likely to be encountered.

RELATIONSHIP WITH CORINTH RIFT LABORATORY DRILLING

The proposed project relates to and complements other ICDP drilling projects dealing with the physics of earthquakes and faulting, including SAFOD, the Taiwan Chelungpu Fault Drilling Project, and especially the Corinth.Rift Laboratory in Greece – the last of these sited in an extensional setting, with implications for the low-angle normal fault paradox.

Initial drilling in the Gulf of Corinth was designed to investigate the mechanical behavior of a large listric normal fault (slip rate ~3.5 mm yr^{-1}), with a key objective of monitoring pore fluid pressure and studying fluid-rock interactions (Cornet et al., 2004; and numerous papers in the same issue). A borehole sunk to a depth of ~1,000 m on the southern shore of the Gulf of Corinth cuts the 60°-dipping Aigion normal fault at a depth of 750 m to 800 m. The width of the damage zone is ~7-12 m, including ~50 cm of gouge. The frictional coefficient of the fault zone material is estimated to be ~ 0.53-0.62. Pore pressure monitoring indicates that the fault acts as a hydraulic barrier separating overpressured fluid compartments with a pore pressure difference of ~ 0.4 MPa.

Reflection imaging and seismological data suggest that the drilled fault soles into a detachment with a dip as low as 13°-18° (Armijo et al., 1996; Rigo et al. 1996; Rietbrock et al., 1996; Sorel, 2000; Sachpazi et al., 2003). However, dips approaching the predicted lock-up angle (Scholz, 2002) are not encountered above a depth of 3-5 km (Sachpazi et al., 2003), and to reach the detachment level, it may be necessary to drill as deep as 6 km from a shipboard platform or as deep as 8-10 km from a land-based site on the north shore of the Gulf. There is also some doubt as to whether observed microseismicity is associated with the inferred detachment or with antithetic faults (Rietbrock et al., 1996). The detachment itself is not well imaged in available seismic reflection data.

No seismicity has been attributed to the Sevier Desert detachment in comparison. However, that fault is widely viewed as recently active on the basis of offsets along hanging-wall structures inferred to terminate against it (e.g., Niemi et al., 2004). The main advantages of the Sevier Desert detachment are that it is well imaged on numerous seismic profiles (Fig. 2), dips consistently at ~11°, and is reached at a depth of 0-4 km from more or less flat public lands, with no significant access problems.

PROPOSED WORKSHOP

We propose to hold an international workshop on "Scientific Drilling in the Sevier Desert Basin" in June or July, 2008, in the State of Utah close to the basin. The purpose of the meeting is to flesh out objectives, strategies and operational details, with input from a much broader constituency of interested scientists than is represented by the PIs, and to develop a consensus on the location of a drill site. This will be informed by an already comprehensive evaluation of existing subsurface data, and by the need to balance optimal science against cost. We aim for ~35-45 participants, with strong international representation; representatives from industry, ICDP, and DOSECC[3], from the Utah Geological Survey and U.S. Geological Survey, from the National Science Foundation (Continental Dynamics) and related NSF programs such as EarthScope[4] and MARGINS[5], as well as from academia; and a full range of pertinent expertise in geology and geophysics, and borehole science/technology. The most important product of the workshop will be a full drilling proposal to be submitted to ICDP in January, 2009.

A workshop venue in Utah, provisionally at Brigham Young University in Provo, will permit inspection of possible drill sites in the Sevier Desert ~100 km to the southwest, and the interpreted outcrop expression of the detachment on the west flank of the Canyon Range. Provo is accessible from the international airport at Salt Lake City ~70 km to the north. The suggested timing is to optimize travel for northern hemisphere participants and weather conditions in the Sevier Desert (elevation ~1,400 m), to gain access to university facilities during the summer recess, and to allow for up to several months between the workshop and the proposal deadline. It would also be preferable to hold the workshop before the 33rd International Geological Congress in Norway (August 6-14, 2008).

A provisional list of participants/invitees, subject to further iteration, is attached as an Appendix.

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[3] Drilling, Observation and Sampling of the Earth's Continental Crust; www.dosecc.org/

[4] http://www.earthscope.org/

[5] http://www.nsf-margins.org/

The plan to hold a workshop will be widely advertised. A final list of participants will be determined by the organizers on the basis of responses received. A provisional program is as follows:

First day: Background and scientific rationale from drilling the Sevier Desert basin; a review of what is known of the geology and geophysics of the basin and the broader Basin and Range Province; update of pertinent results from BARGEN and EarthScope.

Second day: Field trip to the Sevier Desert basin.

Third day: Break-out groups on fault zone sampling and analysis (ductile as well as brittle features); biostratigraphy, magnetostratigraphy and dating (analysis of basin development and hence timing of displacement along the hypothesized detachment); downhole measurements (physical properties, pore pressure, permeability, fluid chemistry, temperature, and stress); coring and logging in the anticipated geological environment (based on existing wells); and drill site evaluation.

Fourth day: Feedback from break-out groups, with discussion; and development of a drilling plan and workshop summary, to be published in EOS and the ICDP Newsletter. Key elements of this feedback will be incorporated into the full drilling proposal.

CANDIDATE DRILL SITES

Candidate drill sites are located east of a line along which the interpreted detachment passes from the Paleozoic-Cenozoic contact into deformed Neoproterozoic and Paleozoic rocks of the Mesozoic orogen, and where the basin fill is < 4 km thick. More than 3 km of fill was recorded at ARCO Pavant Butte (APB in Figs. 2 and 3). The deepest part of the basin (~2.5 s two-way travel time, assuming an acoustic velocity of 3.2 km s^{-1}; Anders et al., 1995, 1998) is interpreted in the northern Sevier Desert basin ~12 km north of Delta (Fig. 5; Wills et al., 2005). In map view, in the southern Sevier Desert basin, this corresponds to locations east of the Clear Lake scarps (CL in Fig. 6). West of that line, a borehole would likely encounter an unconformity at the Paleozoic-Cenozoic contact in any tectonic scenario, and it would be difficult to distinguish the inferred detachment from a Mesozoic thrust fault.

A compelling scientific rationale can be made for a deep hole (4,000 m), and to at least several tens of meters below the Paleozoic-Cenozoic contact to ensure that all strands of the detachment are sampled. Fault rocks (both ductile and brittle) are most likely to be preserved, and to record close to the maximum displacement along the detachment in both the hanging wall and footwall. Hanging-wall displacement decreases up dip to zero where the detachment cuts the youngest strata involved. Footwall mylonites are expected to be best developed and preferentially to have escaped erosion at down-dip locations. In interpreting basin evolution (and the history of displacement along the detachment), it will be useful to sample as complete a stratigraphic record as possible.

According to this rationale, two options are available. In the southern Sevier Desert basin, sites can be considered along seismic profile PC-2/PC-3 between the Cominco American Federal and ARCO Pavant Butte wells (CA and APB in Figs. 2, 4 and 5), and avoiding any thermal effects associated with basalts at Pavant Butte. An advantage of the southern part of the basin is that Oligocene salt appears to be less well developed than in the north. An alternative in the northern Sevier Desert basin, north of the COCORP line, is line PC-1 between the Gulf Gronning and Argonaut Energy Federal wells (GG and AE in Figs. 2, 4 and 5). The detachment is deeper on that line, and thick salt encountered at the AE well (> 1,500 m) may be problematic. In either case, a compromise (to limit cost) would be to consider locations up dip either to the east or towards the east-west high south of Delta, including sites along COCORP Utah Line 1 (Figs. 3 and 5). However, there are obvious advantages to sites relatively close to existing wells, where the gross stratigraphy and drilling environment are already known, and a borehole shallower than ~2,000 m risks not achieving important geological objectives.

BUDGET

Accommodation, meals and venue costs for 4 days: 45 x $600	$27,000
Bus/vehicle charter for field trip	$1,500
Travel expenses prioritized for those from outside the U.S.: 20 x $800	$16,000
Workshop advance preparation in Utah	$1,500
Total estimated cost	**$46,000**

REFERENCES

Abers, G.A., 1991, Possible seismogenic shallow-dipping normal faults in the Woodlark-D'Entrecasteaux extensional province, Papua New Guinea: *Geology,* v. 19, p. 1205-1210.

Abers, G.A., Mutter, C.Z., and Fang Jia, 1997, Shallow dips of normal faults during rapid extension: earthquakes in the Woodlark-D'Entrecasteaux rift system, Papua New Guinea: *J. Geophys. Res.,* v. 102, p. 15,301-15,317.

Allmendinger, R.W., 1992, Fold and thrust tectonics of the western United States exclusive of the accreted terranes, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., *The Cordilleran Orogen: Conterminous U.S.:* Boulder, Colorado, Geol. Soc. America, The Geology of North America, v. G-3, p. 583-607.

Allmendinger, R.W., and Royse, F., Jr., 1995, Is the Sevier Desert reflection of west-central Utah a normal fault?: Comment: *Geology,* v. 23, p. 669-670.

Allmendinger, R.W., Hauge, T., Hauser, E.C., Potter, C.J., Klemperer, S.L., Nelson, D.K., Knuepfer, P., and Oliver, J., 1987, Overview of the COCORP 40°N transect, western United States; the fabric of an orogenic belt: *Geol. Soc. Am. Bull.,* v. 98, p. 308–319.

Allmendinger, R.W., Sharp, J.W., Von Tish, D., Serpa, L., Brown, L., Kaufman, S., and Oliver, J., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range province, Utah, from COCORP seismic-reflection data: *Geology,* v. 11, p. 532-536.

Anders, M.H., and Christie-Blick, N., 1994, Is the Sevier Desert reflection of west-central Utah a normal fault?: *Geology,* v. 22, p. 771-774.

Anders, M.H., and Wiltschko, D.V., 1994, Microfracturing, paleostress and the growth of faults: *J. Struct. Geol.,* v.16, p.795-815.

Anders, M.H., Christie-Blick, N., and Walker, C.D., 2006, Distinguishing between rooted and rootless detachments: A case study from the Mormon Mountains of southeastern Nevada: *J. Geol.,* v. 114, p. 645-664.

Anders, M.H., Christie-Blick, N., and Wills, S., 1995, Is the Sevier Desert reflection of west-central Utah a normal fault?: Reply: *Geology,* v. 23, p. 670.

Anders, M.H., Christie-Blick, N., and Wills, S., 1998, Extensional collapse along the Sevier Desert reflection, northern Sevier Desert basin, western United States: Comment: *Geology,* v. 26, p. 474.

Anders, M.H., Christie-Blick, N., Wills, S., and Krueger, S.W., 2001, Rock deformation studies in the Mineral Mountains and Sevier Desert of west-central Utah: Implications for upper crustal low-angle normal faulting: *Geol. Soc. Am. Bull.,* v. 113, p. 895-907.

Anderson, L.W., and Miller, D.G., 1979, *Quaternary Fault Map of Utah:* Fugro, Inc. Long Beach, California, 35 p.

Armijo, R., Meyer, B., King, G.C.P., Rigo, A., and Papanastassiou, D., 1996, Quaternary evolution of the Corinth Rift and its implications for the Late Cenozoic evolution of the Aegean: *Geophys. J. Int.,* v. 126, p. 11–53.

Armstrong, R.L., 1968, Sevier orogenic belt in Nevada and Utah: *Geol. Soc. Am. Bull.,* v. 79, p. 429-458.

Axen, G.J., 1992, Pore pressure, stress increase, and fault weakening in low-angle normal faulting: *J. Geophys. Res.,* v. 97, p. 8979-8991.

Axen, G.J., 1999, Low-angle normal fault earthquakes and triggering: *Geophys. Res. Lett.,* v. 26, p. 3,693-3,696.

Axen, G.J., 2004, Mechanics of low-angle normal faults, *in* Karner, G.D., Taylor, B., Driscoll, N.W., and Kohlstedt, D.L., eds., *Rheology and Deformation of the Lithosphere at Continental Margins:* New York, Columbia Univ. Press, p. 46-91.

Axen, G.J., and Bartley, J.M., 1997, Field tests of rolling hinges: Existence, mechanical types, and implications for extensional tectonics: *J. Geophys. Res.,* v. 102, p. 20,515-20,537.

Axen, G.J., and Selverstone, J., 1994, Stress-state and fluid-pressure level along the Whipple detachment fault, California: *Geology,* v. 22, p. 835-838.

Axen, G.J., Wernicke, B.P., Skelly, M.J., and Taylor, W.J., 1990, Mesozoic and Cenozoic tectonics of the Sevier thrust belt in the Virgin River Valley area, southern Nevada, *in* Wernicke, B.P., ed., *Basin and Range Extensional Tectonics near the Latitude of Las Vegas, Nevada:* Geol. Soc. Am. Mem. 176, p. 123-153.

Baldwin, S.L., Lister, G.S., Hill, E.J., Foster, D.A., and McDougall, I., 1993, Thermochronologic constraints on the tectonic evolution of active metamorphic core complexes, D'Entrecasteaux Islands, Papua New Guinea: *Tectonics,* v. 12, p. 611-628.

Baldwin, S.L., Monteleone, B., Webb, L.E, Fitzgerald, P.G., Grove, M., and Hill, E.J., 2004, Pliocene eclogite exhumation at plate tectonic rates in eastern Papua New Guinea: *Nature,* v. 431, p. 263-267.

Boncio, P., Brozzetti, F., and Lavecchia., G., 2000, Architecture and seismotectonics of a regional low-angle normal fault zone in central Italy: *Tectonics,* v. 19, p. 1,038-1,055.

Bond, G.C., Christie-Blick, N., Kominz, M.A., and Devlin, W.J., 1985, An early Cambrian rift to post-rift transition in the Cordillera of western North America: *Nature,* v. 316, p. 742-745.

Boyer, S.R., and Allison, M.L., 1987, Estimates of extension in the Basin and Range Province: *Geol. Soc. Am., Abstr. with Progs.,* v. 19, p. 597.

Brady, R., Wernicke, B., and Fryxell, J., 2000, Kinematic evolution of a large-offset continental normal fault system, South Virgin Mountains, Nevada: *Geol. Soc. Am. Bull.,* v. 112, p. 1,375-1,397.

Buck, W.R., 1988, Flexural rotation of normal faults: *Tectonics,* v. 7, p. 959-975.

Burchfiel, B.C., Cowan, D.S., and Davis, G.A., 1992, Tectonic overview of the Cordilleran orogen in the western United States, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., 1992, *The Cordilleran Orogen: Conterminous U.S.:* Boulder, Colorado, Geol. Soc. Am., The Geology of North America, v. G-3, p. 407-479.

Canales J.P., Tucholke, B.E., and Collins, J.A., 2004, Seismic reflection imaging of an oceanic detachment fault: Atlantis megamullion (Mid-Atlantic Ridge, 30°10' N): *Earth Planet. Sci. Lett.,* v. 222, p. 543-560.

Christenson, G.E., Harty, K.M., and Hecker, S., 1987, Quaternary faults and seismic hazards of western Utah, *in* Kopp, R.S., and Cohenour, R.E., eds., *Cenozoic Geology of Western Utah – Sites for Precious Metal and Hydrocarbon Accumulations:* Utah Geol. Assoc. Publ. 16, p. 389-408.

Christie-Blick, N., 1982, Upper Proterozoic and Lower Cambrian rocks of the Sheeprock Mountains, Utah: regional correlation and significance: *Geol. Soc. Am. Bull.,* v. 93, p. 735-750.

Christie-Blick, N., 1997, Neoproterozoic sedimentation and tectonics in west-central Utah: *Brigham Young Univ. Geol. Studies,* v. 42, Part I, p. 1-30.

Christie-Blick, N., and Anders, M.H., in press, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: Discussion: *Geol. Soc. Am. Bull.*

Christie-Blick, N., Anders, M.H., Wills, S., Walker, C.D., and Renik, B., in press, Observations from the Basin and Range Province (western United States) pertinent to the interpretation of regional detachment faults, *in* Karner, G.D., Manatschal, G., and Pinheiro, L., eds., *Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup:* Geol. Soc. London Spec. Publ. No. 282.

Coleman, D.S., and Walker, J.D., 1994, Modes of tilting during extensional core complex development: *Science,* v. 263, p. 215-218.

Coleman, D.S., Bartley, J.M., Walker, J.D., Price, D.E., and Friedrich, A.M., 1997, Extensional faulting, footwall deformation and plutonism in the Mineral Mountains, southern Sevier Desert: *Brigham*

Young Univ. Geol. Studies, v. 42, Part I, p. 203-233.

Collettini, C., and Barchi, M.R., 2002, A low-angle normal fault in the Umbria region (Central Italy): a mechanical model for the related microseismicity: *Tectonophys.,* v. 359, p. 97-115.

Collettini, C., and Holdsworth, R.E., 2004, Fault zone weakening and character of slip along low-angle normal faults: insights from the Zuccale fault, Elba, Italy: *J. Geol. Soc. London,* v. 161, p. 1,039-1,051.

Collettini, C., and Sibson, R. H., 2001, Normal faults, normal friction?: *Geology,* v. 29, p. 927-930.

Coogan, J.C., and DeCelles, P.G., 1996, Extensional collapse along the Sevier Desert reflection, northern Sevier Desert basin, western United States: *Geology,* v. 24, p. 933–936.

Coogan, J.C., and DeCelles, P.G., 1998, Extensional collapse along the Sevier Desert reflection, northern Sevier Desert basin, western United States: Reply: *Geology,* v. 26, p. 475.

Cornet, F.H., Bernard, P., and Moretti, I., 2004, The Corinth Rift Laboratory: *Comptes Rendus Geosci.,* v. 336, No. 4-5, p. 235-241.

Crittenden, M.D., Coney, P.J., and Davis, G.H., eds., 1980, *Cordilleran Metamorphic Core Complexes:* Geol. Soc. Am. Mem. 153, 490 p.

DeCelles, P.G., and Coogan, J.C., 2006, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: *Geol. Soc. Am. Bull.,* v. 118, p. 841-864.

DeCelles, P.G., Lawton, T.F., and Mitra, G., 1995, Thrust timing, growth of structural culminations, and synorogenic sedimentation in the type area of the Sevier orogenic belt, western United States: *Geology,* v. 23, p. 699-702.

Driscoll, N.W., and Karner, G.D., 1998, Lower crustal extension across the northern Carnarvon basin, Australia: Evidence for an eastward dipping detachment: *J. Geophys. Res.,* v. 103, p. 4975-4991.

Faulkner, D.R., Mitchell, M.T., Healy, D., and Heap, M.J., 2006, Slip on "weak" faults by the rotation of regional stress in the fracture damage zone: *Nature,* v. 444, p.922-925.

Fayon, A.K., Whitney, D.L., and Teyssier, C., 2004, Exhumation of orogenic crust: diapiric ascent vs. low-angle normal faulting, *in* Whitney, D.L., Teyssier, C., and Siddoway, C.S., eds., Gneiss *Domes and Orogeny:* Geol. Soc. Am. Spec. Paper 380, p. 129-139.

Floyd, J.S., Mutter, J.C., Goodliffe, A.M., and Taylor, B., 2001, Evidence for fault weakness and fluid flow within an active low-angle normal fault: *Nature,* v. 411, p. 779-783.

Friedmann, S.J., and Burbank, D.W., 1995, Rift and supradetachment basins: Intracontinental extensional endmembers: *Basin Res.,* v. 7, p. 109-127.

Froitzheim, N., and Eberli, G.P., 1990, Extensional detachment faulting in the evolution of a Tethys passive continental margin, Eastern Alps, Switzerland: *Geol. Soc. Am. Bull.,* v. 102, p. 1,297-1,308.

Gessner, K., Ring, U., Johnson, C., Hetzel, R., Passchier, C.W., and Güngör, T., 2001, An active bivergent rolling-hinge detachment system: Menderes metamorphic core complex in western Turkey: *Geology,* v. 29, p. 611–614.

Hamilton, W., 1994, "Sevier Desert detachment," Utah – A nonexistent structure: *Geol. Soc. Am., Abstr. with Progs.,* v. 26, No. 2, p. 57.

Hauge, T.A., 1993, The Heart Mountain detachment, northwestern Wyoming: 100 years of controversy, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M. eds., *Geology of Wyoming:* Geol. Surv. Wyoming Mem. 5, p. 530-571.

Hayman, N.W., Knott, J.R., Cowan, D.S., Nemser, E., and Sarna-Wojcicki, A.M., 2003, Quaternary low-angle slip on detachment faults in Death Valley, California: *Geology,* v. 31, p. 343–346.

Hintze, L.F., 1993, *Geologic History of Utah:* Brigham Young Univ. Geol. Studies Spec. Publ. 7, 202 p.

Hintze, L.F., and Davis, F.D., 2003, *Geology of Millard County, Utah:* Utah Geol. Surv. Bull. 133, 305 p.

Hodges, K., Bowring, S., Davidek, K., Hawkins, D., and Krol, M., 1998, Evidence for rapid displacement on Himalayan normal faults and the importance of tectonic denudation in the evolution of mountain ranges: *Geology,* v. 26, p. 483-486.

Holm, D.K., Snow, J.K., and Lux, D.R., 1992, Thermal and barometric constraints on the intrusive and unroofing history of the Black Mountains: Implications for timing, initial dip, and kinematics of detachment faulting in the Death Valley region, California: *Tectonics,* v. 11, p. 507-522.

Jackson, J.A., 1987, Active normal faulting and crustal extension, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., *Continental Extensional Tectonics:* Geol. Soc. London Spec. Publ. No. 28, p. 3-17.

Jackson, J.A., and White, N.J., 1989, Normal faulting in the upper continental crust: observations from regions of active extension: *J. Struct. Geol.,* v. 11, p. 15-36.

John, B.E., and Foster, D.A., 1993, Structural and thermal constraints on the initiation angle of detachment faulting in the southern Basin Range: The Chemehuevi Mountains case study: *Geol. Soc. Am. Bull.,* v. 105, p. 1091-1108.

John, B.E., Campbell-Stone, E.A., Howard, K.A., and Foster, D.A., 2004, Mechanisms and rates of large-scale continental extension: Examples from the Colorado River extensional corridor, southern Basin and Range: InterMARGINS workshop, Modeling the Extensional Deformation of the Lithosphere (IMEDL), Pontresina (Swiss Alps), Abstr., p. 16.

Jolivet, L., Goffé, B., Monié, P., Truffert-Luxey, C., Patriat, M., and Bonneau, M., 1996, Miocene detachment in Crete and exhumation P-T-t paths of high-pressure metamorphic rocks: *Tectonics,* v. 15, p. 1129-1153.

Karner, G.D., and Driscoll, N.W., 1999, Style, timing, and distribution of tectonic deformation across the Exmouth Plateau, northwest Australia, determined from stratal architecture and quantitative basin modelling, *in* MacNiocaill, C., and Ryan, P.D., eds., *Continental Tectonics:* Geol. Soc. London Spec. Publ. No. 164, p. 271–311.

Karner, G.D., Manatschal, G., and Pinheiro, L., eds., in press, *Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup:* Geol. Soc. London Spec. Publ. No. 282.

Karner, G.D., Taylor, B., Driscoll, N.W., and Kohlstedt, D.L., eds., 2004, *Rheology and Deformation of the Lithosphere at Continental Margins:* New York, Columbia Univ. Press, 352 p.

Kusznir, N.J., Karner, G.D., and Egan, S., 1987, Geometric, thermal and isostatic consequences of detachments in continental lithosphere extension and basin formation, *in* Beaumont, C., and Tankard, A.J., eds., *Sedimentary Basins and Basin-Forming Mechanisms:* Can. Soc. Petrol. Geol. Mem. 12, p. 185-203.

Lavier, L.L., and Manatschal, G., 2006, A mechanism to thin the continental lithosphere at magma-poor margins: *Nature,* v. 440, p. 324-328.

Lavier, L.L., Buck, W.R., and Poliakov, A.N.B., 1999, Self-consistent rolling-hinge model for the evolution of large-offset low-angle normal faults: *Geology,* v. 27, p. 1127-1130.

Lindsey, D.A., Glanzman, R.K., Naeser, C.W., and Nichols, D.J., 1981, Upper Oligocene evaporites in basin fill of Sevier Desert region, western Utah: *Am. Assoc. Petrol. Geol. Bull.,* v. 65, p. 251-260.

Link, P.K., Christie-Blick, N., Devlin, W.J., Elston, D.P., Horodyski, R.J., Levy, M., Miller, J.M.G., Pearson, R.C., Prave, A., Stewart, J.H., Winston, D., Wright, L.A., and Wrucke, C.T., 1993, Middle and Late Proterozoic stratified rocks of the western U.S. Cordillera, Colorado Plateau, and Basin and Range province, *in* Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds., *Precambrian: Conterminous U.S.:* Boulder, Colorado, Geol. Soc. Am., The Geology of North America, v. C-2, p. 463-595.

Lister, G.S., and Davis, G.A., 1989, The origin of metamorphic core complexes and detachment faults formed during Tertiary continental extension in northern Colorado River region, U.S.A.: *J. Struct.*

Geol., v. 11, p. 65-94.

Lister, G.S., Etheridge, M.A., and Symonds, P.A., 1991, Detachment models for the formation of passive continental margins: *Tectonics,* v. 10, p. 1038-1064.

Livaccari, R.F., and Geissman, J.W., 2001, Large-magnitude extension along metamorphic core complexes of western Arizona and southeastern California: Evaluation with palaeomagnetism: *Tectonics,* v. 20, p. 625-648.

Livaccari, R.F., Geissman, J.W., and Reynolds, S.J., 1993, Paleomagnetic evidence for large-magnitude, low-angle normal faulting in a metamorphic core complex: *Nature,* v. 361, p. 56-59.

Manatschal, G., 1999, Fluid- and reaction-assisted low-angle normal faulting: evidence from rift-related brittle fault rocks in the Alps (Err nappe, eastern Switzerland): *J. Struct. Geol.,* v. 21, p. 777-793.

Manatschal, G., Froitzheim, N., Rubenach, M., and Turrin, B.D., 2001, The role of detachment faulting in the formation of an ocean-continent transition: insights from the Iberia Abyssal Plain, *in* Wilson, R.C.L., Whitmarsh, R.B., Taylor, B., and Froitzheim, N., eds., *Non-Volcanic Rifting of Continental Margins: A Comparison of Evidence from Land and Sea:* Geol. Soc. London Spec. Publ. No. 187, p. 405-428.

Manatschal, G., M
üntener, O., Lavier, L.L., Minshull, T.A., and Peron-Pinvidic, G., in press, Observations from the Alpine Tethys and Iberia/Newfoundland margins pertinent to the interpretation of continental break-up, *in* Karner, G.D., Manatschal, G., and Pinheiro, L., eds., *Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup:* Geol. Soc. London Spec. Publ. No. 282.

McDonald, R.E., 1976, Tertiary tectonics and sedimentary rocks along the transition: Basin and Range province to plateau and thrust belt province, Utah, *in* Hill, J.G., ed., *Symposium on Geology of the Cordilleran Hingeline:* Denver, Rocky Mountain Assoc. Geol., p. 281-317.

Miller, E.L., Gans, P.B., and Garing, J., 1983, The Snake Range décollement: An exhumed mid-Tertiary ductile-brittle transition: *Tectonics,* v. 2, p. 239-263.

Miller, M.B., and Pavlis, T.L., 2005, The Black Mountains turtlebacks: Rosetta stones of Death Valley tectonics: *Earth-Sci. Rev.,* v. 73, p. 115-138.

Miller, M.G., 1991, High-angle origin of the currently low-angle Badwater turtleback fault, Death Valley, California: *Geology,* v. 19, p. 372-375.

Mitchell, G.C., and McDonald, R.E., 1987, Subsurface Tertiary strata, origin, depositional model and hydrocarbon potential of the Sevier Desert basin, west central Utah, *in* Kopp, R.S., and Cohenour, R.E., eds., *Cenozoic Geology of Western Utah – Sites for Precious Metal and Hydrocarbon Accumulations:* Utah Geol. Assoc. Publ. 16, p. 533-556.

Mitra, G., and Sussman, A.J., 1997, Structural evolution of connecting splay duplexes and their implication for critical taper: An example based on geometry and kinematics of the Canyon Range culmination, Sevier belt, central Utah*: J. Struct. Geol.,* v. 19, p. 503–521.

Niemi, N.A., Wernicke, B.P., Friedrich, A.M., Simons, M., Bennett, R.A., and Davis, J.L., 2004, BARGEN continuous GPS data across the eastern Basin and Range province, and implications for fault system dynamics: *Geophys. J. Internat.,* v. 159, p. 842-862.

Osmundsen, P.T., Andersen, T.B., Markussen, S., and Svendby, A.K., 1998, Tectonics and sedimentation in the hangingwall of a major extensional detachment: the Devonian Kvamshesten basin, western Norway: *Basin Res.,* v. 10, p. 197-212.

Otton, J.K., 1995, Western frontal fault of the Canyon Range: Is it the breakaway zone of the Sevier Desert detachment?: *Geology,* v. 23, p. 547-550.

Otton, J.K., 1996, Western frontal fault of the Canyon Range: Is it the breakaway zone of the Sevier Desert detachment?: Reply: *Geology,* v. 24, p 668-669.

Oviatt, C.G., 1989, *Quaternary Geology of a Part of the Sevier Desert, Millard County, Utah:* Utah Geol. Min. Surv. Spec. Studies 70, 41 p.

Planke, S., and Smith, R.B., 1991, Cenozoic extension and evolution of the Sevier Desert basin, Utah, from seismic reflection, gravity and well log data: *Tectonics,* v. 10, p. 345-365.

Proffett, J.M., 2002, Kinematic evolution of a large-offset continental normal fault system, South Virgin Mountains, Nevada: Discussion: *Geol. Soc. Am. Bull.,* v. 114, p. 124–126.

Proffett, J.M., Jr., 1977, Cenozoic geology of the Yerington District, Nevada, and implications for nature and origin of Basin and Range faulting: *Geol. Soc. Am. Bull.,* v. 88, p. 247-266.

Reston, T.J., Krawczyk, C.M., and Klaeschen, D., 1996, The S reflector west of Galcia (Spain): Evidence from prestack depth migration for detachment faulting during continental breakup: *J. Geophys. Res.,* v. 101, p. 8,075-8,091.

Rietbrock, A., Tiberi, C., Scherbaum, F., and Lyon-Caen, H., 1996, Seismic slip on a low-angle normal fault in the Gulf of Corinth: Evidence from high-resolution cluster analysis of microearthquakes: *Geophys. Res. Lett.,* v. 23, p. 1817-1820.

Rigo, A., Lyon-Caen, H., Armijo, R., Deschamps, A., Hatzfeld, D., Makropoulos, K., Papadimitriou, P., and Kassaras, I., 1996, A microseismic study in the western Gulf of Corinth (Greece): implications for large-scale normal faulting mechanisms: *Geophys. J. Int.,* v. 126, p. 663-688.

Royse, F., Jr., 1993, Case of the phantom foredeep: Early Cretaceous in west-central Utah: *Geology,* v. 21, p. 133-136.

Sachpazi, M., Clement, C., Laigle, M., Hirn, A., and Roussos, N., 2003, Rift structure, evolution, and earthquakes in the Gulf of Corinth, from reflection seismic images: *Earth Planet. Sci. Lett.,* v. 216, p. 243-257.

Scholz, C.H., 2002, *The Mechanics of Earthquakes and Faulting:* Cambridge, England, Cambridge Univ. Press, 2nd ed., 471 p.

Scholz, C.H., and Hanks, T.C., 2004, The strength of the San Andreas fault: A discussion, *in* Karner, G.D., Taylor, B., Driscoll, N.W., and Kohlstedt, D.L., eds., *Rheology and Deformation of the Lithosphere at Continental Margins:* New York, Columbia Univ. Press, p. 261-283.

Scott, R.J., and Lister, G.S., 1992, Detachment faults: Evidence for a low-angle origin: *Geology,* v. 20, p. 833-836.

Sibson, R.H., 1985, A note on fault reactivation: *J. Struct. Geol.,* v. 7, p. 751-754.

Smith, M.T., Dickinson, W.R., and Gehrels, G.E., 1993, Contractional nature of Devonian-Mississippian Antler tectonism along the North American continental margin: *Geology,* v. 21, p. 21-24.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the eastern Basin and Range: inferences on structural style from seismic reflection data, regional tectonics, and thermal-mechanical models of brittle-ductile deformation: *J. Geophys. Res.,* v. 89, p. 5,733-5,762.

Snow, J.K., and Wernicke, B.P., 2000, Cenozoic tectonism in the central Basin and Range: Magnitude, rate, and distribution of upper crustal strain: *Am. J. Sci.,* v. 300, p. 659-719.

Sorel, D., 2000, A Pleistocene and still-active detachment fault and the origin of the Corinth-Patras rift, Greece: *Geology,* v. 28, p. 83-86.

Stewart, J.H., 1972, Initial deposits in the Cordilleran geosyncline: evidence of a Late Precambrian (<850 m.y.) continental separation: *Geol. Soc. Am. Bull.,* v. 83, p. 1345-1360.

Stockli, D.F., Linn, J.K., Walker, J.D., and Dumitru, T.A., 2001, Miocene unroofing of the Canyon Range during extension along the Sevier Desert detachment, west central Utah: *Tectonics,* v. 20, p. 289–307.

Taylor, B., Goodliffe, A.M., and Martinez, F., 1999, How continents break up: Insights from Papua New Guinea: *J. Geophys. Res.,* v. 104, p. 7,497-7,512.

Von Tish, D.B., Allmendinger, R.W., and Sharp, J.W., 1985, History of Cenozoic extension in central Sevier Desert, west-central Utah, from COCORP seismic reflection data: *Am. Assoc. Petrol. Geol. Bull.,* v. 69, p. 1077-1087.

Weissel, J.K., and Karner, G.D., 1989, Flexural uplift of rift flanks due to mechanical unloading of the lithosphere during extension: *J. Geophys. Res.,* v. 94, p. 13919-13950.

Wernicke, B., 1981, Low-angle normal faulting in Basin and Range Province: Nappe tectonics in an extending orogen: *Nature,* v. 291, p. 645-648.

Wernicke, B., 1985, Uniform-sense normal simple shear of the continental lithosphere: *Can. J. Earth Sci.,* v. 22, p. 108-125.

Wernicke, B., 1992, Cenozoic extensional tectonics of the U.S. Cordillera, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., *The Cordilleran Orogen: Conterminous U.S.:* Boulder, Colorado, Geol. Soc. Am., The Geology of North America, v. G-3, p. 553-581.

Wernicke, B., 1995, Low-angle normal faults and seismicity: A review: *J. Geophys. Res.,* v. 100, p. 20,159-20,174.

Wernicke, B., and Axen, G.J., 1988, On the role of isostasy in the evolution of normal fault systems: *Geology,* v. 16, p. 848-851.

Wernicke, B., and Burchfiel, B.C., 1982, Modes of extensional tectonics: *J. Struct. Geol.,* v. 4, p. 105-115.

Wernicke, B.P., Bennett, R.A., Davis, J.L., Niemi, N.A., House, M.A., Abolins, M.I., and Brady, R.J., 1998, Building large-scale continuous GPS networks: *EOS, Trans. Am. Geophys. Union,* v. 79, p. F206.

Wernicke, B.P., Friedrich, A.M., Niemi, N.A., Bennett, R.A., and Davis, J.L., 2000, Dynamics of plate boundary fault systems from Basin and Range Geodetic Network (BARGEN) and geologic data: *GSA Today,* v. 10, No. 11, p. 1-7.

Westaway, R., 1999, The mechanical feasibility of low-angle normal faulting: *Tectonophys.,* v. 308, p. 407-443.

Wills, S., and Anders, M.H., 1996, Western frontal fault of the Canyon Range: Is it the breakaway zone of the Sevier Desert detachment?: Comment: *Geology,* v. 24, p. 667-668.

Wills, S., and Anders, M.H., 1999, Tertiary normal faulting in the Canyon Range, eastern Sevier Desert: *J. Geol.,* v. 107, p. 659-681.

Wills, S., Anders, M.H., and Christie-Blick, N., 2005, Pattern of Mesozoic thrust surfaces and Tertiary normal faults in the Sevier Desert subsurface, west-central Utah: *Am. J. Sci.,* v. 305, p. 42-100.

BIOGRAPHICAL SKETCHES

The six listed PIs represent a balance between U.S. and non-U.S. participation, those who have worked in west-central Utah/Basin and Range Province and those who have not, both outcrop and subsurface experience (including ICDP and ODP/IODP), structural, geophysical and stratigraphic expertise, experience in both extensional and passive margin settings (modern and ancient), and expertise with borehole technology. We also represent a full range of opinion on the significance of extensional detachments and on the geology of the Sevier Desert basin. Our consensus view is that the time is ripe to make substantial progress towards new understanding of low-angle normal faults, and that the Sevier Desert is among the places where that new understanding may be achieved.

NICHOLAS CHRISTIE-BLICK

Curriculum Vitae

Lamont-Doherty Earth Observatory of Columbia University
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On leave until June, 2007 at Department of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand.
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Date and place of birth: 3 June, 1953; St Albans, UK. U.S./British citizen.

Degrees

Ph.D., University of California, Santa Barbara, 1979 (Geology). Advisor: John C. Crowell.

B.A., University of Cambridge (King's College), UK, 1974 (Natural Sciences/Geology).

Professional Career

Professor, Department of Earth and Environmental Sciences and Lamont-Doherty Earth Observatory of Columbia University[6], Palisades, New York 10964-8000.
[**Assistant Professor**, 1983-1987. **Associate Professor**, 1987-1993. Promotion to tenure, 1989. **Professor**, 1993 to present. **Associate Chair**, 2002-2004. **Chair**, and **Deputy Director**, Lamont-Doherty Earth Observatory, 2004-2006.]

Senior Research Geologist (Basin Exploration Division), Exxon Production Research Company[7], P.O. Box 2189, Houston, Texas 77252-2189, 1981-1983.
[**Research Geologist**, 1980-1981.]

Postdoctoral Assistant Research Geologist, Department of Geological Sciences[8], University of California, Santa Barbara, California 93106, 1979-1980.

Current Research

Diverse topics in sedimentary geology and tectonics, with emphasis on challenging conventional thinking and attempting to resolve outstanding debates and paradoxes. Examples include the way in which sedimentation is modulated by sea-level change, deformation and other factors; extensional tectonics in the western U.S.; and the geology of the Neoproterozoic Era. I am a participant in and co-proponent for Integrated Ocean Drilling Program (IODP) Expedition 313, Shallow-Water Drilling of the New Jersey Continental Shelf in 2007-2008, a multinational research effort that is being underwritten in part by ICDP. I was co-chief scientist for Ocean Drilling Program (ODP) Leg 174A, New Jersey Mid-Atlantic Sea-Level Transect, in 1997.

Relevant Publications

A total of 90 articles published, in press, in review or in revision. Relevant examples:

Anders, M.H., and Christie-Blick, N., 1994, Is the Sevier Desert reflection of west-central Utah a normal fault?: *Geology,* v. 22, p. 771-774.

Anders, M.H., Christie-Blick, N., and Wills, S., 1995, Is the Sevier Desert reflection of west-central Utah a normal fault?: Reply: *Geology,* v. 23, p. 670.

Anders, M.H., Christie-Blick, N., and Walker, C.D., 2006, Distinguishing between rooted and rootless detachments: A case study from the Mormon Mountains of southeastern Nevada: *J. Geol.,* v. 114, p. 645-664.

[6] Formerly Department of Geological Sciences (before 1996) and Lamont-Doherty Geological Observatory (before 1993).
[7] Now ExxonMobil Upstream Research Company (since 2000).
[8] Now Department of Earth Science (since 2005).

Anders, M.H., Christie-Blick, N., and Wills, S., 1998, Extensional collapse along the Sevier Desert reflection, northern Sevier Desert basin, western United States: Comment: *Geology,* v. 26, p. 474.

Anders, M.H., Christie-Blick, N., Wills, S., and Krueger, S.W., 2001, Rock deformation studies in the Mineral Mountains and Sevier Desert of west-central Utah: Implications for upper crustal low-angle normal faulting: *Geol. Soc. Am. Bull.,* v. 113, p. 895-907.

Austin, J.A., Jr., Christie-Blick, N., Malone, M.J., et al., 1998, Proceedings of the Ocean Drilling Program, Initial Reports, v. 174A, Continuing the New Jersey Mid-Atlantic Sea-Level Transect: College Station, Texas, Ocean Drilling Program, 324 p.

Bond, G.C., Christie-Blick, N., Kominz, M.A., and Devlin, W.J., 1985, An early Cambrian rift to post-rift transition in the Cordillera of western North America: *Nature,* v. 316, p. 742-745.

Christie-Blick, N., 1982, Upper Proterozoic and Lower Cambrian rocks of the Sheeprock Mountains, Utah: Regional correlation and significance: *Geol. Soc. Am. Bull.,* v. 93, p. 735-750.

Christie-Blick, N., 1983, Structural geology of the southern Sheeprock Mountains, Utah: Regional significance, *in* Miller, D.M., Todd, V.R., and Howard, K.A., eds., *Tectonic and Stratigraphic Studies in the Eastern Great Basin:* Geol. Soc. Am. Mem. 157, p. 101-124.

Christie-Blick, N., 1997, Neoproterozoic sedimentation and tectonics in west-central Utah: *Brigham Young Univ. Geol. Studies,* v. 42, Part I, p. 1-30.

Christie-Blick, N., and Anders, M.H., in press (May/June, 2007 issue), Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: Discussion: *Geol. Soc. Am. Bull.*

Christie-Blick, N., and Biddle, K.T., 1985, Deformation and basin formation along strike-slip faults, *in* Biddle, K.T., and Christie-Blick, N., eds., *Strike-Slip Deformation, Basin Formation, and Sedimentation:* Soc. Econ. Paleont. Min. Spec. Publ. No. 37, p. 1-34.

Christie-Blick, N., and Driscoll, N.W., 1995, Sequence stratigraphy: *Ann. Rev. Earth Planet. Sci.,* v. 23, p. 451-478.

Christie-Blick, N., Anders, M.H., Wills, S., Walker, C.D., and Renik, B., in press (June, 2007), Observations from the Basin and Range Province (western United States) pertinent to the interpretation of regional detachment faults, *in* Karner, G.D., Manatschal, G., and Pinheiro, L., eds., *Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup:* Geol. Soc. London Spec. Publ. No. 282.

Driscoll, N.W., Hogg, J.R., Christie-Blick, N., and Karner, G.D., 1995, Extensional tectonics in the Jeanne d'Arc Basin, offshore Newfoundland: implications for the timing of break-up between Grand Banks and Iberia, *in* Scrutton, R.A., Stoker, M.S., Shimmield, G.B., and Tudhope, A.W., eds., *The Tectonics, Sedimentation and Palaeoceanography of the North Atlantic Region:* Geol. Soc. London Spec. Publ. No. 90, p. 1-28.

Levy, M., and Christie-Blick, N., 1989, Pre-Mesozoic palinspastic reconstruction of the eastern Great Basin (western United States): *Science,* v. 245, p. 1454-1462.

Levy, M., and Christie-Blick, N., 1991, Tectonic subsidence of the early Paleozoic passive continental margin in eastern California and southern Nevada: *Geol. Soc. Am. Bull.,* v. 103, p. 1590-1606.

Metzger, J.M, Flemings, P.B., Christie-Blick, N., Mountain, G.S., Austin, J.A., Jr., and Hesselbo, S.P., 2000, Late Miocene to Pleistocene sequences at the New Jersey outer continental shelf (ODP Leg 174A, Sites 1071 and 1072): *Sed. Geol.,* v. 134, p. 149-180.

Pekar, S.F., Christie-Blick, N., Miller, K.G., and Kominz, M.A., 2003, Quantitative constraints on the origin of stratigraphic architecture at passive continental margins: Oligocene sedimentation in New Jersey, U.S.A.: *J. Sed. Res.,* v. 73, p. 227-243.

Walker, C.D., Anders, M.H., and Christie-Blick, N., in press (March, 2007 issue), Kinematic evidence for down-dip movement on the Mormon Peak detachment: *Geology.*

Wills, S., Anders, M.H., and Christie-Blick, N., 2005, Pattern of Mesozoic thrust surfaces and Tertiary normal faults in the Sevier Desert subsurface, west-central Utah: *Am. J. Sci.,* v. 305, p. 42-100.

MARK H. ANDERS
Curriculum Vitae

Professional Preparation

University of Colorado, Boulder	Geology	B.A., 1975
University of Michigan, Ann Arbor	Geology	M.S., 1982
University of California, Berkeley	Geology	Ph.D., 1989

Appointments

Associate Professor of Geology, Department of Earth and Environmental Sciences and Senior Research Scientist, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York; 1993, tenured 1996

Assistant Professor of Geology, Department of Geological Sciences and Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York; 1989-1993

Research Assistant and Teaching Assistant, Department of Geology and Geophysics, University of California at Berkeley; 1983–1989

Research Geologist, U.S. Bureau of Reclamation, Engineering and Research Center; Denver, Colorado; Seismotectonics Section, 1981–1983

Research Geologist, U.S. Bureau of Mines, Research Center; Denver, Colorado; Rock Mechanics Branch, 1979–1981

Principal Research Interests

Structural geology, tectonics and stratigraphy; including normal faulting, fault growth, fault zone deformation, neotectonics and the Yellowstone hotspot.

Publications

Examples from a total of over 50 publications:

Aharonov, E. and **Anders, M.H.** (2006). Hot water: A possible solution to the Heart Mountain detachment problem?: *Geology,* v. 34, n. 3. 165-168.

Anders, M.H. and Wiltschko, D.V.(1994). Microfracturing, paleostress and the growth of faults: *Journal of Structural Geology*, v. 16, no. 6, p. 795-815.

Anders, M.H., Aharonov, E., Walsh, J.J. (2000). Stratification of granular media at the base of large slide blocks: implications for mode of emplacement: *Geology,* v. 28, 971-974.

Anders, M.H., and Christie-Blick, N. (1994). Is the Sevier Desert reflection of west-central Utah a normal fault?: *Geology*, vol. 22, n. 9, p. 771-774.

Anders, M.H., and Schlische, R.W., (1994). Overlapping faults, intrabasin highs, and the growth of normal faults: *Journal of Geology*, v. 102, p. 165-180.

Anders, M.H., Christie-Blick, N. and Walker, C.D. (2006). Distinguishing between rooted and rootless detachments: a case study from the Mormon Mountains of southeastern Nevada: *Journal of Geology,* v. 114, n. 6, p. 645-664.

Anders, M.H., Christie-Blick, N., and Wills, S. (1995). Is the Sevier Desert reflection of west-central Utah a normal fault? Reply: *Geology*, v. 23. p. 670.

Anders, M.H., Christie-Blick, N., Wills, S. (1998). Extensional collapse along the Sevier Desert detachment, northern Sevier Desert basin, western United States: Comment: *Geology,* v. 26, p. 474.

Anders, M.H., Gregory-Wodzicki, K.M., Spiegelman, M. (2002). A critical evaluation of late Tertiary accelerated uplift rates for the Eastern Cordillera, central Andes of Bolivia: *Journal of Geology,* v. 110, n. 1, p. 89-100.

Anders, M.H., Spiegelman, M., Rodgers, D.W., and Hagstrum, J.T. (1993). The growth of fault-bounded tilt blocks: *Tectonics*, v. 12, no. 6, p. 1451-1459.

Anders, M.H., Wills, S., Christie-Blick, N., and Krueger, S.W. (2001). Rock deformation studies in the Mineral Mountains and the Sevier Desert of of west-central Utah: Implications for upper crustal low-angle normal faulting: *Geological Society of America Bulletin*, v. 113, p. 895-907.

Christie-Blick, N. and **Anders, M.H.** (in press, May/June 2007 issue). Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah, Discussion: *Geological Society of America Bulletin***.**

Christie-Blick, N., **Anders, M.H**., Wills, S., Walker. C.D. and Renick, B. (in press, June 2007). Observations from the Basin and Range Province (western United States) pertinent to interpretation of regional detachment faults. *in Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup*, eds. G. Karner, G. Manatschal, and L. Pinheiro. Special Publication 282 of the *Geological Society, London*.

Dawers, N. H., **Anders, M.H**., and Scholz, C.H. (1993). Growth of normal faults: displacement-length scaling: *Geology*, v., 21, no. 12, p. 1107-1110.

Dawers, N.H., and **Anders, M.H**.(1995) Displacement-length scaling and fault linkage: *Journal of Structural Geology*, v. 17, n. 5, p. 607-614.

Schlische, R.W., and **Anders, M.H**. (1996). Stratigraphic effects and tectonic implications of the growth of normal faults and extensional basins, in Reconstructing the history of Basin and Range extension using sedimentology and stratigraphy, editor K. Beratan: *Geological Society of America Special Publication 303*, p. 183-203.

Scholz, C.H., and **Anders, M.H**.(1994). The permeability of faults; in The Mechanical Involvement of Fluids in Faulting, editors S. Hickman, R. Sibson, and R. Bruhn, *U.S. Geological Survey -Red Book LXIII*, OF Report 94-228, p. 247-253.

Scholz, C.H., Dawers, N.H., Yu, J., **Anders, M.H**., and Cowie, P.A. (1993). Fault growth and fault-scaling laws: preliminary results: *Journal of Geophysical Research*, v. 98, no. B12, p. 21,951-21,961.

Simpson, D.W., and **Anders, M.H**. (1992). Tectonics and topography of the western U.S. - an example of digital map making: *GSA Today*, v. 2, no. 6, p. 118-121.

Walker, C.D., **Anders, M.H**., Christie-Blick, N. (in press, March 2007 issue). Kinematic evidence for downslope movement on the Mormon Peak detachment: *Geology*.

Wills, S., and **Anders, M.H.**, (1999). Tertiary normal faulting in the Canyon Range of the eastern Sevier Desert Utah: *Journal of Geology*, v. 107, 659-681.

Wills, S., and **Anders, M.H**.(1996) Western frontal fault of the Canyon Range: Is it the breakaway zone of the Sevier Desert detachment?: Comment: *Geology,* p. 667-668.

Wills, S., **Anders, M.H**., Christie-Blick, N. (2005). Pattern of Mesozoic thrust surfaces and Tertiary normal faults in the Sevier Desert subsurface, west-central Utah: *American Journal of Science*, v. 305, p. 42-100.

GEORG DRESEN

Curriculum Vitae

University of Potsdam and GeoForschungsZentrum Potsdam
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Research Interests

Rock physics and geomechanics, rheology of rocks, earth material properties, physics of earthquakes and faulting, geodynamics, role of crystal defects in deformation, macroscopic constitutive behaviour of rocks, rock transport properties

Academic Training

Habilitation, 1990, Technical University of Darmstadt.
Dr.rer.nat., 1983, University of Bonn (sehr gut)
Diploma (Geology), 1979, University of Bonn (sehr gut)

Professional Experience

27. 01.1993 - :	Professor of Geology University of Potsdam and GeoForschungsZentrum Potsdam
01.08.1992 - :	Head of GFZ-Section 3.2: *Deformation and Rheology*
1989-92:	Research Scientist Massachusetts Institute of Technology (M.I.T.) Cambridge, Mass.
1984-89:	University Assistant T U Darmstadt

Funded Projects (total)

12 DFG
1 Nato

Professional Service Activities

2004- : Vice-President Sub-Division *Rock Physics and Geomaterials*, European Geosciences Union (EGU)
1998-2001: Steering Committee *Physical Properties of Earth Materials,* American Geophysical Union (AGU) Mineral and Rock Physics
1995-1999: Associate Editor *Journal of Geophysical Research-Solid Earth,* AGU
Convener Euro-Conference on Rock Physics and Geomechanics 2004
Convener AGU Annual Meeting 2003, Sessions T17
Convener AGU Annual Meeting 2001, Sessions T06 I-V
Conf. Vol. Guest Editor Int. J. Earth Sci., 90, 2001

Awards and Nominations

Visiting Professor at Ecole Polytechnique, Paris 2004 (invited)
Heisenberg-Fellowship 1992
DFG-Research Fellowship 1989

Invited Lectures (2006)

Univ. Göttingen, 2006
European Geosciences Union (EGU), Vienna, 2006
19th Kongsberg Seminar, Oslo, 2006
IODP-ICDP Workshop on Fault Zone Drilling, Miyazaki, Japan 2006

Peer-Reviewed Publications (2002-2006)

30. Kenkmann, T. and G. Dresen *(2002):* Dislocation Microstructure and Phase Distribution in a Lower Crustal Shear Zone – an Example from the Ivrea – Zone, Italy, *Int. J. Earth Sci. (Geol. Rundsch.),* 91, 445-458.
31. Xiao, X., R. Wirth and G. Dresen *(2002)*: Diffusion Creep of Anorthite-Quartz Aggregates, *J. Geophys. Res*. 107 (B11), 2279, doi:10.1029/2001JB000789,2002.
32. Zang, A.; Stanchits, S. & Dresen, G. *(2002)*. Acoustic Emission-Controlled Triaxial Rock Fracture and Friction Tests. In: *Dyskin, A.V., Hu, X. & Sahouryeh, E. (eds.) Structural Integrity and Fracture. The International Conference on Structural Integrity and Fracture, Perth, Australia.:* 289-294.
33. Rybacki, E., M. P. Paterson, R. Wirth, and G. Dresen (*2003*): Rheology of calcite-quartz aggregates deformed to large strain in torsion, *J. Geophys. Res.,* 108, B2, 2089, doi:10.1029/2002JB001833, 2003.
34. Dimanov, A., M.P. Lavie, G. Dresen, J. Ingrin and O. Jaoul (*2003*): Creep of polycrystalline anorthite and diopside, *J. Geophys. Res.,* 108, NO. B1, 2061, doi:10.1029/2002JB001815, 2003.
35. Heinemann, S., R. Wirth and G. Dresen *(2003):* TEM Study of a Special Grain Boundary in a Synthetic K-Feldspar Bicrystal: Manebach Twin, *Phys. Chem. Min*., 30, 125-130.
36. Backers, T., G. Dresen, N. Fardin, and O. Stephansson (*2003*): Effect of loading rate on mode I fracture toughness, roughness and micromechanics of sandstone, *Int. J. Rock Mech. Min. Sci.,* 40, 425-43.
37. Milsch, H., W. Heinrich and G. Dresen *(2003):* Reaction-Induced Fluid Flow in Synthetic Quartz-Bearing Marbles, *Contrib. Min. Petrol.,* 146, 286-296.
38. Dresen, G. and Y. Gueguen (*2004*): Damage and Rock Physical Properties, in Y. Gueguen and M. Bouteca (eds.) Mechanics of fluid saturated rocks, *Elsevier Science, Int. Geophys. Ser.* 169-217.
39. Rybacki, E. and G. Dresen (*2004*): Deformation Mechanism Maps for Feldspar Rocks, *Tectonophysics,* 382, 173-187.
40. Backers, T., S. Stanchits and G. Dresen (*2005*): Tensile Fracture Propagation and Acoustic Emission Activity in Sandstone: The Effect of Loading Rate, *Int. J. Rock Mech. Min. Sci.,* 42, 1094-1101.
41. Dimanov, A. and G. Dresen (*2005*): Rheology of Synthetic Anorthite-Diopside Aggregates: Implications for Ductile Shear Zones*, J. Geophys. Res.,* 110,B07203, doi:10.1029/2004JB003431.
42. Heinemann S., R. Wirth, M. Gottschalk and G. Dresen (2005): Synthetic [100] tilt grain boundaries in forsterite: 9.9° to 21.5°, *Phys. Chem. Min.,*32, 229-240.
43. Rybacki, E., M. Gottschalk, R. Wirth and G. Dresen (*2006*): Influence of water fugacity and activation volume on the flow properties of fine-grained anorthite aggregates, *J. Geophys. Res.*, 111, B03203, 10.1029/2005JB003663.
44. Bohnhoff, M., Grosser, H., and G. Dresen, (*2006*): Strain partitioning and stress rotation at the North Anatolian Fault after the 1999 Izmit Mw=7.4 earthquake, *Geophys. J. Int.,* 166, 373-385.
45. Stanchits, S. Vinciguerra, and G. Dresen (*2006*): Ultrasonic velocities, acoustic emission characteristics and crack damage of basalt and granite, *Pure Appl. Geophys.*, 163, 975-994.
46. Fortin, J., S. Stanchits, G. Dresen, and Y. Guéguen (2006): Acoustic emission and velocities associated with the formation of compaction bands in sandstone, *J. Geophys. Res.*, 111, B10203, doi: 10.1029/2005JB003854
47. Hoffmann-Rothe, A., N. Kukowski, G. Dresen, H. Echtler, O. Oncken, J. Klotz, E. Scheuber and A. Kellner (*2006*): Oblique convergence along the Chilean margin: Partitioning, margin-parallel faulting and force interaction at the plate interface, in: Oncken O, Strecker M, Franz G, Ramos V (eds) Andean Geodynamcs, Frontiers in Geosciences 1, Springer, in press.

GORDON STUART LISTER

Curriculum Vitae

Nationality:	Australian
Place of Birth:	Brisbane, Queensland, Australia
Date of Birth:	21st September, 1948
Languages:	English, Dutch

Employment Record (10 years):

2003-present	**Professor (and group leader of structure-tectonics team)** Research School of Earth Sciences, The Australian National University,
2002 - present	**Director-at-large** Australian Computational Earth Systems Simulator Major National Research Facility (ACcESS MNRF)
1989-2003	**Director** Australian Crustal Research Centre, Monash University
1987-2003	**Professor of Earth Sciences** Monash University
1992-1999	**Research Coordinator** Australian Geodynamics Cooperative Research Centre
1990-1993	**Founding Director** Victorian Institute of Earth and Planetary Sciences

Qualifications

1968	**Bachelor of Science (Geology)** Townsville University College, University of Queensland,
1969	**First Class Honours (Geology)** James Cook University of North Queensland
1975	**Ph.D. (Geophysics)** Research School of Earth Sciences, The Australian National University

Honours and Awards

2001	**Bruce Hobbs Medal** Excellence in Structural Geology
2002	**ISI Highly Cited Researcher** (within top 250 in Earth Sciences)

Research Drivers

Planetary Tectonics - evolution of the Alpine-Himalayan mountain chain.
Reconstruction - geodynamically constrained global tectonic reconstruction.
Simulation - creation of geologically specific process simulation software.
Reading Rocks - the science of fabric and microstructural analysis.
Structural Geology and Tectonics - from the microscale to the continent scale.

Current Research Grants Funded

The role of inversion cycles in the evolution of the European Alps (ARC Discovery).
Tectonic reconstruction of the evolution of the Alpine-Himalayan orogenic chain (ARC Discovery).
The Australian Computational Earth Systems Simulator (The ACcESS MNRF).

Selected Publications

Schellart, W.P., Lister, G.S. and Toy, V.G. 2006. A Late Cretaceous and Cenozoic reconstruction of the Southwest Pacific region: Tectonics controlled by subduction and slab rollback processes. *Earth Science Reviews* **76**, 191-233.

Forster, M. A., Lister, G. S. and Keay, S. M. 2005. Analysis of $^{40}Ar/^{39}Ar$ apparent age spectra measured from Syros, Cyclades, Greece: application of the method of asymptotes and limits. *Contributions to Mineralogy and Petrology* **150**, 523-545.

Rosenbaum, G. and Lister, G.S. 2005. The Western Alps from the Jurassic to Oligocene: spatio-temporal constraints and evolutionary reconstructions. *Earth Science Reviews* **69**, 281-306.

Schellart, W.P. and Lister, G.S. 2005. The role of the East Asian active margin in widespread extensional and strike-slip deformation in East Asia. *Journal of the Geological Society* **162**, 959-972.

Betts, P. G., Giles, D. and Lister, G. S. 2004. Aeromagnetic patterns of half-graben and basin inversion: implications for sediment hosted massive sulphide Pb-Ag-Zn exploration. *Journal of Structural Geology* **26**, 1137-1156.

Forster, M. A. and Lister, G. S. 2004. The interpretation of $^{40}Ar/^{39}Ar$ apparent age spectra produced by mixing: application of the method of asymptotes and limits. *Journal of Structural Geology* **26**, 287-305.

Giles, D., Betts, P. G. and Lister, G. S. 2004. The 1.8 - 1.5 Ga links between the north and south Australian cratons and the palaeo- to meso-Proterozoic configuration of Australia. *Tectonophysics* **380**, 27-41.

Miller, M.S., Kennett, B.L., and Lister, G.S. 2004. Imaging changes in morphology, geometry, and physical properties of the subducting Pacific plate along the Izu-Bonin-Mariana Arc. *Earth and Planetary Science Letters* **224**, 363-370.

Rosenbaum, G. and Lister, G.S., 2004. Neogene and Quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and the Sicilian Meghrebides. *Tectonophysics* **23**, C1013.

Rosenbaum, G., Lister, G. S. and Duboz, C. 2004. The Mesozoic and Cenozoic motion of Adria (central Mediterranean): a review of constraints and limitations. *Geodinamica Acta* **17**, 19-33.

Betts, P. G., Giles, D. and Lister, G. S. 2003. Tectonic environment of shale-hosted massive sulphide Pb-Zn-Ag deposits of Proterozoic northeastern Australia. *Economic Geology* **98**, 557-576.

Forster, M. A. and Lister, G. S. 2003a. Cretaceous metamorphic core complexes in the Otago Schist, New Zealand.*Australian Journal of Earth Sciences* **50**, 181-198.

Schellart, W. P., Jessell, M. W. and Lister, G. S. 2003. Asymmetric deformation in the back-arc region of the Kuril Arc, Northwest Pacific: some insights from analogue modelling. *Tectonics* **22**, 1047-1065.

Betts, P. G. and Lister, G. S. 2002. Geodynamically indicated targetting strategy for shale-hosted massive sulfide Pb-Zn-Ag mineralisation in the Western Fold Belt, Mt Isa terrane. *Australian Journal of Earth Sciences* **49,** 985-1010.

Betts, P. G., Giles, D., Lister, G. S. and Frick, L. R. 2002. Evolution of the Australian lithosphere. *Australian Journal of Earth Sciences* **49**, 661-696.

Giles, D., Betts, P. and Lister, G. S. 2002. A far-field continental back-arc setting for the 1.8-1.6 Ga basins of northeastern Australia. *Geology* **30**, 823-826.

Keay, S. and Lister, G. S. 2002. African provenance for the metasediments and metaigneous rocks of the Cyclades, Aegean Sea, Greece. *Geology* **30**, 235-238.

Rawling, T. J. and Lister, G. S. 2002. Large scale structure of the high-pressure Pam-Panie region of New Caledonia. *Journal of Structural Geology* **24**, 1239-1258.

Rosenbaum, G., Lister, G. S. and Duboz, C. 2002. Relative motions of Africa, Iberia and Europe during Alpine orogeny. *Tectonophysics* **359**, 117-129.

Schellart, W. P., Lister, G. S. and Jessell, M. W. 2002a. Analogue modeling of arc and backarc deformation in the New Hebrides Arc and North Fiji Basin. *Geology* **30**, 311-31

Lister, G. S., Forster, M. A., and Rawling, T. J. 2001. Episodicity during orogenesis. *Geological Society, London, Special Publication* **184**, 89-113.

Betts, P. and Lister, G. S. 2001. A comparison of the “strike-slip” versus the “episodic rift-sag” hypothesis for the origin of the Isa superbasin. *Australian Journal of Earth Sciences* **48**, 265-280.

GIANRETO MANATSCHAL

Curriculum Vitae

Université Louis Pasteur, CGS-EOST, 1 rue Blessig, F-67 084, France
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Date of birth : November 1, 1965, Sta. Maria, Switzerland.

Education

1991- 1995 Ph. D. in Earth Sciences, ETH Zürich, Switzerland.
1990-1991 Diploma in Geology (M. Sc. equivalent), ETH Zürich, Switzerland.
1986-1991 Studies of Earth Sciences, ETH Zürich, Switzerland

Thesis Advisors: Daniel Bernoulli (ETH Zürich) and Niko Froitzheim (University of Basel)

Experience

2003- Université Louis Pasteur, Strasbourg, Professor for Tectonics.
1999- 2003 Université Louis Pasteur, Strasbourg, Assistant Professor.
1997- 1999 ETH Zürich, Postdoctoral fellow.
1995- 1997 Danish Lithosphere Center, Post-doctoral fellow.

Professional Affiliations

- American Geophysical Union, Geologische Vereinigung (D), Société Géologique de France, Schweizerische Geologische Gesellschaft

Related Professional Experience

- **EUG Session 2001** : Contrasting processes of continental rift and passive margin development : comparison of results from the modern océans and orogenic belts Covenors : A. Robertson, H.-C. Larsen, R. Whitmarsh and G. Manatschal.
- **Annual Meeting of the Swiss Academy of Natural Sciences (SANW) 2002 in Davos:** Workshop B: Birth and Early evolution of Alpine Ocean Basins. Convenors: D. Bernoulli, S. Schmid and G. Manatschal.
- **EGS 2002, Session SE2.08** : Birth and Evolution of the Oceans: Architecture, Deep Structure and Active Processes from Margins to Ridges. Convenors : E. Gracia ; Co-Convenor L. Menezes Pinheiro and G. Manatschal.
- **EGS-AGU-EUG Joint Assembly 2003, Session TS13:** Continental Margin Dynamics: Conjugate Margins & Mantle Exhumation during Rifting. Convenors : K. Louden, J. Hopper, T. Minshull, O. Müntener and G. Manatschal.
- **Intermargins Workshop Pontresina, Switzerland, 2004:** Modelling the Extensional Deformation of the Lithosphere,**.** Convenors : G. Karner, G. Manatschal and L. Pinheiro
- **AGU Fall Meeting 2005, Session T33 :** Mechanisms of Continental Extension During Basin and Rifted-Margin Formation. Convenors : M. Perez-Gussinye, G. Manatschal, J. Hopper, C.R. Ranero
- **IODP Workshop on continental breakup 2006 :** Pontresina, Switzerland, (locale organizer)
- **International Workshop on Ocean Continent Transitions 2007:** Paris ; Convenors : P. Huchon, G. Manatschal, G.Péron-Pinvidic

Awards

1991 Silver medal and distinction for diploma thesis
2000 Hans Cloos prize for young scientists Geologische Vereinigung (Germany)

Selected Publications

Manatschal, G. and Nievergelt, P. (1997). A continent-ocean transition recorded in the Err and Platta nappes (Eastern Switzerland). **Eclogae geol. Helv**. 90/1, 3-27.

Manatschal, G. (1999). Fluid-and reaction-assisted low-angle normal faulting: evidence from rift-related brittle fault rocks in the Alps (Err nappe, eastern Switzerland), **J. Struct. Geol**., 21, 777-793.

Manatschal, G. and Bernoulli, D. (1999). Architecture and tectonic evolution of non-volcanic margins: Present-day Galicia and ancient Adria. **Tectonics**, 18 (6) ,1099-1199.

Manatschal, G., Marquer, D. and Früh-Green, G.L. (2000). Channelized fluid flow and mass transfer along a rift-related detachment fault (Eastern Alps, southeastern Switzerland). **Geol. Soc. Amer. Bull**., 112 (1), 21-33.

Manatschal, G., Froitzheim, N., Rubenach, M. J. and Turrin, B. (2001). The role of detachment faulting in the formation of an ocean-continent transition: insights from the Iberia Abyssal Plain. In: Non-volcanic rifting of continental margins: evidence from land and sea. Wilson, R. C. L., Whitmarsh, R. B., Taylor, B. and Froitzheim, N.(eds). **Geol. Soc. London, Spec. Publ**.,187, 405-428.

Wilson, R.C.L., Manatschal, G. and Wise, S. (2001). Rifting along non-volcanic passive margins: stratigraphic and seismic evidence from the Mesozoic succession of the Alps and western Iberia. In: Non-volcanic rifting of continental margins: evidence from land and sea. Wilson, R. C. L., Whitmarsh, R. B., Taylor, B. and Froitzheim, N.(eds). **Geol. Soc. London, Spec. Publ.**, 187, 429-452.

Desmurs, L., Manatschal, G. and Bernoulli, D. (2001). The Steinmann trinity revisited: mantle exhumation and magmatism along an ocean-continent transition: the Platta nappe, eastern Switzerland. In: Non-volcanic rifting of continental margins: evidence from land and sea. Wilson, R. C. L., Whitmarsh, R. B., Taylor, B. and Froitzheim, N.(eds). **Geol. Soc. London, Spec. Publ**., 187, 235-266.

Whitmarsh, R.B., Manatschal G. and Minshull, T.B. (2001). Evolution of magma-poor continental margins from rifting to seafloor spreading. **Nature**, 413, 150-154.

Desmurs, L., Müntener, O. and Manatschal, G. (2002). Onset of magmatic accretion within a magma-poor passive margin: a case study from the Platta ocean-continent transition, eastern Switzerland. **Contributions to Mineralogy and Petrology**, 144, 365-382.

Hölker, A. Manatschal, G., Holliger, K. and Bernoulli, D. (2003). Tectonic nature and seismic response of top-basement detachment faults in magma-poor rifted margins. **Tectonics,** 22/4, 1035, doi : 10.1029/2001TC001347.

Manatschal, G., Müntener, O., Desmurs, L and Bernoulli, D. (2003). An ancient ocean-continent transition in the Alps : the Totalp, Err-Platta, and Malenco units in the eastern Central Alps (Graubünden and northern Italy). **Eclogae geol. Helv.,** 96, 131-146.

Manatschal G. (2004). New models for evolution of magma-poor rifted margins based on a review of data and concepts from West Iberia and the Alps. **International Journal of Earth Sciences**, 93 : 432-466.

Lavier, L. and Manatschal, G. (2006) Mechanism to thin the continental lithosphere at magma poor margins. **Nature,** 440/16, doi: 10.1038, 324-328.

Manatschal, G., Engström, A., Desmurs, L., Schaltegger, U. Cosca, M., Müntener, O. and Bernoulli, D. (2006). What is the tectono-metamorphic evolution of continental break-up: The example of the Tasna Ocean-Continent-Transition. **Journal of Structural Geology**, 28; 1849-1869.

Müntener, O. and Manatschal, G. (2006) High degrees of melt extraction recorded by spinel harzburgite of the Newfoundland margin: The role of inheritence and consequences for the evolution of the southern North Atlantic. **Earth and Planetary Science Letters**, 252; 437-452

Manatschal, G., Müntener, O., Lavier, L.L., Minshull, T.A., and Peron-Pinvidic, G. (in press) Observations from the Alpine Tethys and Iberia/Newfoundland margins pertinent to the interpretation of continental break-up, *in* Karner, G.D., Manatschal, G., and Pinheiro, L., eds., Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup: **Geol. Soc. London Spec. Publ**. No. 282.

Péron-Pinvidic, G., Manatschal, G., Minshull, T.A. and Sawyer, D.S. (in press) The tectono-sedimentary evolution of the deep Iberia-Newfoundland margin: evidence for a complex break-up history. **Tectonics**, in press.

Karner, G.D., Manatschal, G., and Pinheiro, L., eds., (in press) Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup: **Geol. Soc. London Spec. Publ**. No. 282.

BRIAN PHILIP WERNICKE

Curriculum Vitae

Address and Phone: Division of Geological and Planetary Sciences
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Date and Place of Birth: 26 June 1958
Los Angeles, California

Marital Status: Married; two children (ages 8 and 11)

Education: PhD Earth and Planetary Sciences
Massachusetts Institute of Technology, 1982

BS Geological Sciences
University of Southern California, 1978

Current Position:

2001-present Chandler Family Professor of Geology, California Institute of Technology

Positions Held:

2004-2005	Visiting Scientist, Ocean Research Institute, University of Tokyo
2003-2004	Crosby Distinguished Lecturer, Massachusetts Institute of Technology
1992-2001	Professor of Geology, California Institute of Technology
1990	Visiting Professor, California Institute of Technology
1987-1992	Professor of Geology, Harvard University
1986-1987	Associate Professor of Geology, Harvard University
1983-1986	Assistant Professor of Geology, Harvard University
1982-1983	Assistant Professor of Geology, Syracuse University

Relevant Publications:

1. **Wernicke**, Brian, and Axen, G.J., 1988, On the role of isostasy in the evolution of normal fault systems: Geology, v. 16, p. 848-851.
2. **Wernicke,** Brian, 1992, Cenozoic extensional tectonics of the U.S. Cordillera: in Burchfiel, B.C., P.W. Lipman, and M.L. Zoback, eds., The Cordilleran Orogen: Conterminous U.S., The Geology of North America, G-3: Geological Society of America, Boulder, Colorado, p. 553-582.
3. **Wernicke,** Brian, 1995, Low-angle normal faults and seismicity: A review: Journal of Geophysical Research, v. 100, p. 20,159-20,174.
4. Friedrich, A.M., **Wernicke**, B.P., Niemi, N.A., Bennett, R.A. and Davis, J.L., 2003, Comparison of geodetic and geologic data from the Wasatch region, Utah and implications for the spectral character of earth deformation at periods of ten to ten million years: Journal of Geophysical Research, v. 108, doi 10.1029/2001JB000682.
5. Park, S.K. and **Wernicke,** B.P., 2003, Electrical conductivity images of Quaternary faults and Tertiary detachments in the California Basin and Range: Tectonics, v. 22 1030, doi:10.1029/2001TC001324.
6. Niemi, N.A., **Wernicke,** B.P., Friedrich, A.M., Simons, M., Bennett, R.A., Davis, J.L., 2004, BARGEN continuous GPS data across the eastern Basin and Range province, and implications for fault system dynamics: Geophysical Journal International, v. 159, p. 842-862, doi:10.1111/j.1365-246X.2004.02454.x.
7. **Wernicke**, B., Davis, J. L., Bennett, R. A., Normandeau, J. E., Friedrich, A. M., and Niemi, N. A., 2004, Tectonic implications of a dense continuous GPS velocity field at Yucca Mountain, Nevada:

Journal of Geophysical Research, v. 109, n. B12404, doi:10.1029/2003JB002832.

8. McQuarrie, N. and **Wernicke**, B.P., 2005, An animated tectonic reconstruction of southwestern North America since 36 Ma: Geosphere, v. 1, no., 3, p. 1-20. doi: 10.1130/GES00016.1
9. Davis, J. L., **Wernicke,** B. P., Bisnath, S., Niemi, N. A., and Elosegui, P., 2006, Subcontinental-scale crustal velocity changes along the Pacific-North America transform plate boundary, Nature, v. 441, doi:10.1038/nature.04781, p. 1131-1134.
10. Verdel, C., **Wernicke**, B. P., Ramezani, J., Hassanzadeh, J., and Renne, P.R., 2007, Geology and thermochronology of Tertiary Cordilleran-style metamorphic core complexes in the Saghand region of central Iran, Geological Society of America Bulletin, v. 119 (in press).

Collaborators:
Graduate advisor& recent scientific collaborators not included in above publications (last five years):
B.C. Burchfiel - PhD thesis advisor, MIT
A. R. Prave, St. Andrews University
J.W. Geissman, University of New Mexico
S. A. Bowring, MIT
G. H. Gehrels, University of Arizona
T. M. Harrison, UCLA

Postdoctoral Research Associates:
Joan Fryxell (1984 PhD, U of North Carolina)
Peter Tilke (1986 PhD, MIT)
Yemane Asmerom (1988 PhD, U. of Arizona)
Barbara Sheffels (1989 PhD, MIT)
Stephen Getty (1990 PhD, Brown University)
J. Kent Snow (1990 PhD, Harvard University)
Martha House (1995 PhD, MIT)
Anke Friedrich (1998 PhD, MIT)
Nadine McQuarrie (2001 PhD, U. of Arizona)
Bernard Guest (2004 PhD, UCLA)
Kevin Mahan (2005 PhD, U. Massachusetts)
Rebecca Flowers (2005 PhD, MIT)

Doctoral Students:
Elaine Aliberti (PhD 1988)
Bryan Kriens (PhD 1988)
J. Kent Snow (PhD 1990)
Gary Axen (PhD 1991)
Daniel Holm (PhD 1992)
Alexandra Moore (PhD 1993)
Robert Brady (PhD 1998)
Mark Abolins (PhD 1998)
Nathan Niemi (PhD 2002)
Ryan Petterson (current)
Charles Verdel (current)

Masters Students:
Wanda Taylor (MS 1982)
Barbara Ellis (MS 1982)
Miguel Doblas (MS 1984)

APPENDIX: PROVISIONAL LIST OF WORKSHOP PARTICIPANTS/INVITEES

The following list is intended as a point of departure, with a target of 35-45 attendees. There are undoubtedly others who ought to be included as we attempt to broaden representation in expertise and from the international community. Attention has been given to the range of expertise that will be needed in fault zone sampling and analysis; biostratigraphy, magnetostratigraphy and dating; downhole measurements (physical properties, pore pressure, permeability, fluid chemistry, temperature, and stress); coring and logging; and drill site evaluation – though not broken out in those terms in this preliminary compilation. A wealth of experience now exists, as a result of burgeoning interest in scientific drilling, and as represented at the May, 2006 IODP-MI/ICDP Workshop on Fault Zone Drilling in Japan.[9] A final list of participants will be determined by the organizers following advertisement of the workshop, and on the basis of responses received.

Nicholas Christie-Blick (Lamont-Doherty Earth Observatory)
Mark Anders (Lamont-Doherty Earth Observatory)
Georg Dresen (Universität Potsdam and GeoForschungsZentrum Potsdam, Germany)
Gordon Lister (Australian National University, Australia)
Gianreto Manatschal (Université Louis Pasteur, Strasbourg, France)
Brian Wernicke (California Institute of Technology)

Geoffrey Abers (Boston University)
Richard Allis (Utah Geological Survey)
Richard Allmendinger (Cornell University)
Gary Axen (New Mexico Tech)
Suzanne Baldwin (Syracuse University)
John Bartley (University of Utah)
Richard Bennett (University of Arizona)
Kathi Beratan (University of Pittsburg)
Robert Bohannon (U.S. Geological Survey)
Günter Borm (Universität Potsdam and GeoForschungsZentrum Potsdam, Germany)
Jean Braun (Australian National University, Australia)
Stephanie Brichau (University of Kansas)
Ronald Bruhn (University of Utah)
Roger Buck (Lamont-Doherty Earth Observatory)
Clark Burchfiel (Massachusetts Institute of Technology)
Jean-Pierre Burg (ETH Zürich, Switzerland)
Allan Carroll (University of Wisconsin)
Barbara Carrapa (University of Wyoming)
Clem Chase (University of Arizona)
Frederick Chester (Texas A and M University)
Drew Coleman (University of North Carolina)
Cristiano Collettini (Università degli Studi di Perugia, Italy)
James Coogan (Western State College, Colorado)
François-Henri Cornet (Institut de Physique du Globe de Paris, France)

9 http://www.iodp.org/fault-zone-drilling/

Darrel Cowan (University of Washington)
Patience Cowie (University of Edinburgh, UK)
Peter DeCelles (University of Arizona)
Earl Davis (Geological Survey of Canada, Pacific Geoscience Center)
Gregory Davis (University of Southern California)
John Dewey (University of California, Davis)
Rebecca Dorsey (University of Oregon)
William Dickinson (University of Arizona)
Neal Driscoll (Scripps Institution of Oceanography)
Mihai Ducea (University of Arizona)
James Faulds (University of Nevada, Reno)
Paul Fitzgerald (Syracuse University)
Don Forsythe (Brown University)
David Foster (University of Florida, Gainsville)
Julio Friedmann (University of Maryland)
Anke Friedrich (Universität Hannover, Germany)
James Gaherty (Lamont-Doherty Earth Observatory)
Philip Gans (University of California, Santa Barbara)
Robert Gawthorpe (University of Manchester, UK)
John Geissman (University of New Mexico)
Klaus Gessner (University of Western Australia, Perth)
Alan Glazner (University of North Carolina)
Andy Gleadow (Monash University, Australia)
David Goldberg (Lamont-Doherty Earth Observatory)
Bernhard Grasemann (University of Vienna, Austria)
Gilles Guerin (Lamont-Doherty Earth Observatory)
Warren Hamilton (U.S. Geological Survey and Colorado School of Mines)
Suzanne Hecker (U.S. Geological Survey)
Steve Hickman (U.S. Geological Survey)
Lehi Hintze (Brigham Young University)
John Hopper (Texas A&M University)
Brian Horton (University of Texas, Austin)
Eugene Humphreys (University of Oregon)
James Jackson (University of Cambridge, UK)
Martin Jackson (Bureau of Economic Geology, University of Texas)
Suzanne Janecke (Utah State University, Logan)
Barbara John (University of Wyoming)
Leonard Johnson (NSF, Continental Dynamics)
Laurent Jolivet (Université Pierre et Marie Curie, Paris, France)
Paul Kapp (University of Arizona)
Garry Karner (ExxonMobil, Houston)
Charlotte Keen (Geological Survey of Canada)
Dennis Kent (Rutgers University)

Gaku Kimura (University of Tokyo, Japan)
Simon Klemperer (Stanford University)
Roy Kligfield (University of Colorado, Boulder)
Nick Kusznir (University of Liverpool, UK)
Vicki Langenheim (U.S. Geological Survey)
Tim Lawton (New Mexico State University, Las Cruces)
Luc Lavier (University of Texas, Austin)
Mike Leeder (Leeds University, UK)
Arthur Lerner-Lam (Lamont-Doherty Earth Observatory)
David Lindsey (U.S. Geological Survey)
Timothy Little (Victoria University of Wellington, New Zealand)
Richard Livaccari (Mesa State College, Colorado)
David Lockner (U.S. Geological Survey)
Malka Machlus (Lamont-Doherty Earth Observatory)
Chris Marone (Pennsylvania State University)
John McBride (Brigham Young University)
Ken McClay (University of London, UK)
Nadine McQuarrie (Princeton University)
Elizabeth Miller (Stanford University)
Ken Miller (Rutgers University)
Gautam Mitra (University of Rochester)
Isabelle Moretti (Institut Français du Pétrole, France)
Meredith Nettles (Lamont-Doherty Earth Observatory)
Dennis Nielsen (DOSECC)
Nathan Niemi (University of Michigan)
James Otton (U.S. Geological Survey)
Charles Oviatt (Kansas State University, Manhattan)
Stephen Pekar (CUNY, Queens College)
Lothar Ratschbacher (Technische Universität Bergakademie Freiberg, Germany)
Byrdie Renik (Lamont-Doherty Earth Observatory)
Tim Reston (University of Birmingham, UK)
Steve Reynolds (Arizona State University)
Andreas Rietbrock (University of Liverpool, UK)
Uwe Ring (University of Canterbury, New Zealand)
Mousumi Roy (University of New Mexico)
Frank Royse (Chevron, retired, Arvada, Colorado)
Demian Saffer (Pennsylvania State University)
Roy Schlische (Rutgers University)
Jim Schmitt (Montana State University)
Michel Séranne (Université Montpellier 2, France)
Donna Shillington (Lamont-Doherty Earth Observatory)
Richard Sibson (University of Otago, New Zealand)
Robert Smith (University of Utah)

John Solum (U.S. Geological Survey)
Jon Spencer (Arizona Geological Survey)
Jack Stewart (U.S. Geological Survey)
Bernhard Stöckhert (Ruhr-Universität Bochum, Germany)
Daniel Stockli (University of Kansas)
Aviva Sussman (Los Alamos National Laboratory, New Mexico)
Wanda Taylor (University of Nevada)
George Thompson (Stanford University)
Douglas Walker (University of Kansas)
Nicky White (University of Cambridge)
Stewart Wills (AAAS)
Martha Withjack (Rutgers University)
Mark Zoback (Stanford University)
Mary Lou Zoback (U.S. Geological Survey)

Representative of ICDP (Steve Hickman)
Representative of NSF, Continental Dynamics and EarthScope (Leonard Johnson)
Representative of DOSECC (David Dinter, Barbara John, John McBride, David Goldberg, Ken Miller, Dennis Nielsen)
Representative of MARGINS (Geoff Abers)
Representative of U.S. Geological Survey (numerous)
Representative of Utah Geological Survey (Richard Allis)
Representative of University of Utah (John Bartley, Ronald Bruhn, David Dinter, Robert Smith)
Representative of Brigham Young University (Lehi Hintze, John McBride)
Representative of petroleum industry (Garry Karner, Frank Royse; one or more involved in past drilling in the Sevier Desert basin)