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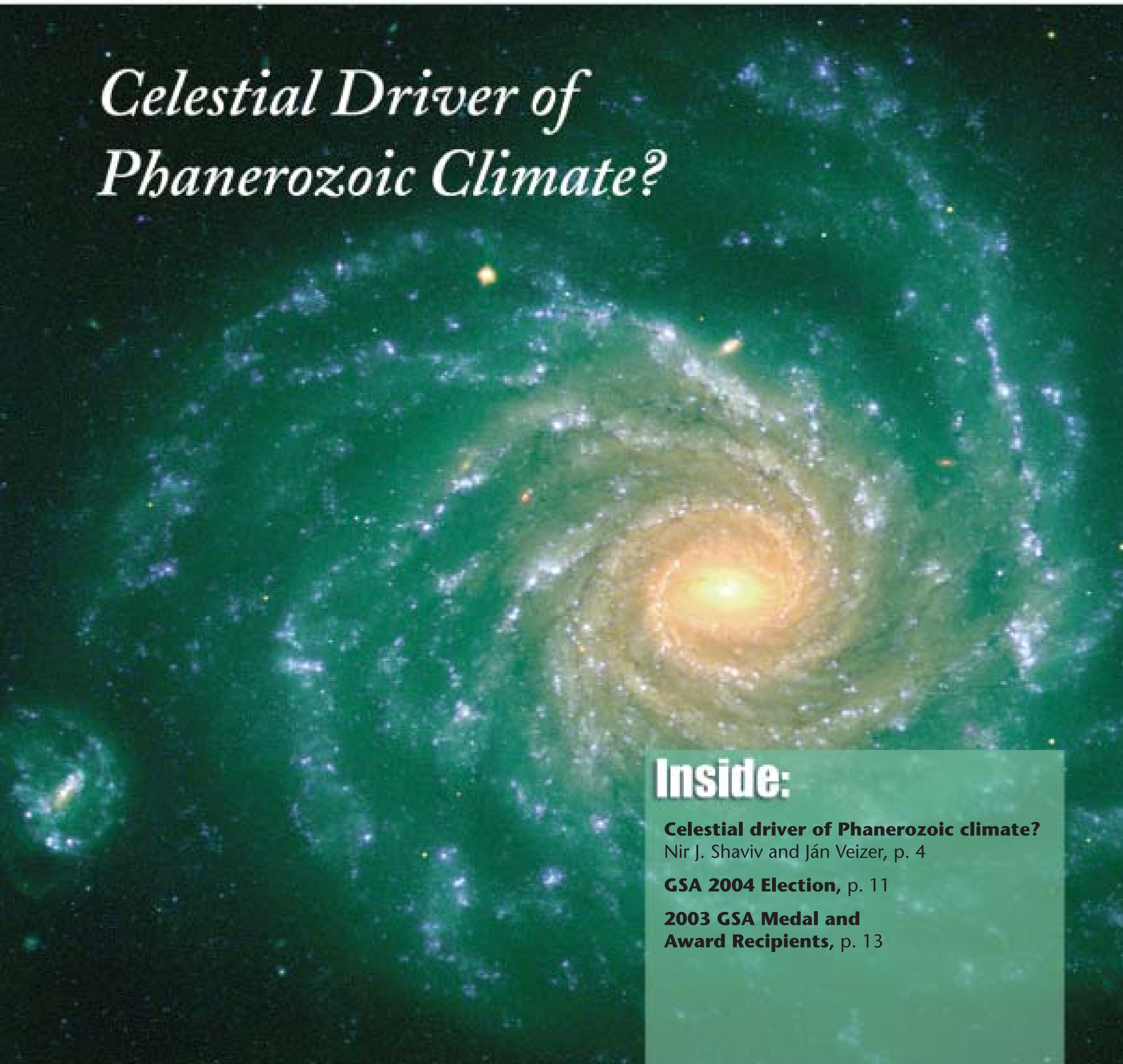

Celestial Driver of Phanerozoic Climate?

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GSA TODAY

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Cover: Our Milky Way galaxy is smaller and has better organized arms, but is not unlike the spiral galaxy NGC 1232. This image of NGC 1232 was obtained on September 21, 1998, by the European Southern Observatory (available at http://www.eso.org/outreach/press-rel/pr-1998/pr-14-98.html). See "Celestial driver of Phanerozoic climate?" by Nir Shaviv and Ján Veizer, p. 4–10. (Spiral Galaxy NGC 1232-VLTUT1 + FOTS1; ESO PR Photo 37d/98 [23 September 1998]; © European Southern Observatory; used with permission.)

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Celestial driver of Phanerozoic climate?

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ABSTRACT

Atmospheric levels of CO_2 are commonly assumed to be a main driver of global climate. Independent empirical evidence suggests that the galactic cosmic ray flux (CRF) is linked to climate variability. Both drivers are presently discussed in the context of daily to millennial variations, although they should also operate over geological time scales. Here we analyze the reconstructed seawater paleotemperature record for the Phanerozoic (past 545 m.y.), and compare it with the variable CRF reaching Earth and with the reconstructed partial pressure of atmospheric CO_2 (pCO_2). We find that at least 66% of the variance in the paleotemperature trend could be attributed to CRF variations likely due to solar system passages through the spiral arms of the galaxy. Assuming that the entire residual variance in temperature is due solely to the CO_2 greenhouse effect, we propose a tentative upper limit to the long-term "equilibrium" warming effect of CO_2, one which is potentially lower than that based on general circulation models.

CLIMATE ON GEOLOGICAL TIME SCALES

The record of climate variations during the Phanerozoic (past 545 m.y.), based on temporal and spatial patterns of climate-sensitive sedimentary indicators, shows intervals of tens of millions of years duration characterized by predominantly colder or predominantly warmer episodes, called icehouses and greenhouses (Frakes et al., 1992), respectively (Fig. 1). Superimposed on these are higher-order climate oscillations, such as the waning and waxing of ice sheets during the past 1 m.y. The recurring icehouse/greenhouse intervals were postulated to be a consequence of a plethora of causative factors, from celestial to planetary, including geographic distribution of continents, oceanic circulation patterns, atmospheric composition, or any combination of these. Lately, the consensus opinion favors atmospheric CO_2 as a principal climate driver for most time scales, from billions of years (CO_2 supergreenhouse, snowball Earth [Kasting and Ackerman, 1986; Hoffman et al., 1998]), to decadal and annual (Intergovernmental Panel on Climate Change [IPCC], 2001). Past climate variations should therefore correlate positively with coeval atmospheric pCO_2 levels.

For the Phanerozoic, estimates of atmospheric pCO_2 levels (Fig. 1) are based on model consideration and proxy data. Presently, three such estimates exist: the GEOCARB III model (Berner and Kothavala, 2001) and its precursors, and the reconstructions of Berner and Streif (2001) and Rothman (2002). These reconstructions rely, to a greater or lesser degree, on the same isotope databases of Veizer et al. (1999). However, they produce internally inconsistent outcomes and the curves do not show any clear correlation with the paleoclimate record.

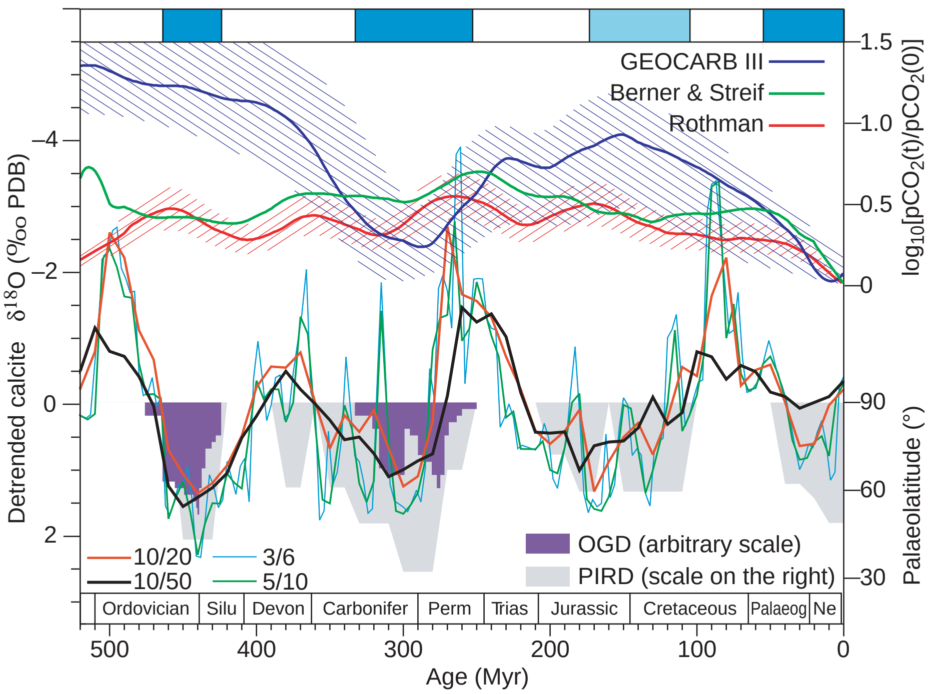

Figure 1. Phanerozoic climatic indicators and reconstructed pCO_2 levels. The bottom set of curves are the detrended running means of $\delta^{18}O$ values of calcitic shells over the Phanerozoic (Veizer et al., 2000). 3/6, 5/10, 10/20 and 10/50 indicate running means at various temporal resolutions (e.g., 3/6 means step 3 m.y., window 6 m.y. averaging). The paleolatitudinal distribution of ice rafted debris (PIRD) is on the right-hand vertical axis. The available, Paleozoic, frequency histograms of other glacial deposits (OGD)—such as tillites and glacial marine strata—are dimensionless. The blue bars at the top represent cool climate modes (icehouses) and the white bars are the warm modes (greenhouses), as established from sedimentological criteria (Frakes and Francis, 1998; Frakes et al., 1992). The lighter blue shading for the Jurassic-Cretaceous icehouse reflects the fact that true polar ice caps have not been documented for this time interval. The upper set of curves describes the reconstructed histories of the past pCO_2 variations (GEOCARB III) by Berner and Kothavala (2001), Berner and Streif (2001) and Rothman (2002). The $pCO_2(0)$ is the present-day atmospheric CO_2 concentration. All data are smoothed using a running average of 50 m.y. with 10 m.y. bins. The hatched regions depict the uncertainties quoted in the Rothman and the GEOCARB reconstructions.

The poor correlation of the modeled pCO_2 with the observed Phanerozoic climate trends (Frakes et al., 1992; Veizer et al., 2000; Boucot and Gray, 2001) suggest either that the pCO_2 models may be in need of improvement, or, if one of them is validated, that the CO_2 is not likely to be the principal climate driver. In that case, what could be an alternative driving force of climate on geological time scales?

Decompositions of the $\delta^{18}O$ and paleoclimate trends[1] (Veizer et al., 2000) display a dominant cyclic component of ~135 ± 9 m.y. For $\delta^{18}O$, this is regardless of the temporal resolution (on m.y. time scales) adopted for deconvolution of the signal. There are no terrestrial phenomena known that recur with this frequency, particularly taking into account the regular near-sinusoidal fashion (Fig. 1; Wallmann, 2001) of the $\delta^{18}O$ data. This regular pattern implies that we may be looking at a reflection of celestial phenomena in the climate history of Earth.

CELESTIAL CLIMATE DRIVER

Growing evidence, such as the correlations between paleoclimate records and solar and cosmic ray activity indicators (e.g., ^{10}Be, ^{14}C), suggests that extraterrestrial phenomena are responsible for at least some climatic variability on time scales ranging from days to millennia (Friis-Christensen and Lassen, 1991; Tinsley and Deen, 1991; Soon et al., 1996; Svensmark, 1998; Beer et al., 2000; Egorova et al., 2000; Soon et al., 2000; Björck et al., 2001; Bond et al., 2001; Hodell et al., 2001; Kromer et al., 2001; Labitzke and Weber, 2001; Neff et al., 2001; Todd and Kniveton, 2001; Pang and Yau, 2002; Solanki, 2002). These correlations mostly surpass those, if any, for the coeval climate and CO_2. Empirical observations indicate that the climate link could be via solar wind modulation of the galactic cosmic ray flux (CRF) (Tinsley and Deen, 1991; Svensmark, 1998; Marsh and Svensmark, 2000; Todd and Kniveton, 2001; Shaviv, 2002a, 2002b) because an increase in solar activity results not only in enhanced thermal energy flux, but also in more intense solar wind that attenuates the CRF reaching Earth. The CRF, in turn, correlates convincingly with the low-altitude cloud cover on time scales from days (Forbush phenomenon) to decades (sun spot cycle). The postulated causation sequence is therefore: brighter sun ⇒ enhanced thermal flux + solar wind ⇒ muted CRF ⇒ less low-level clouds ⇒ less albedo ⇒ warmer climate. Diminished solar activity results in an opposite effect. The apparent departure from this pattern in the 1990s (Solanki, 2002) may prove to be a satellite calibration problem (Marsh and Svensmark, 2003). The CRF–cloud-cover–climate link is also physically feasible because the CRF governs the atmospheric ionization rate (Ney, 1959; Svensmark, 1998), and because recent theoretical and experimental studies (Dickenson, 1975; Harrison and Aplin, 2001; Eichkorn et al., 2002; Yu, 2002; Tinsley and Yu, 2003) relate the CRF to the formation of charged aerosols, which could serve as cloud condensation nuclei (CCN), as demonstrated independently by ground-based and airborne experiments (Harrison and Aplin, 2001; Eichkorn et al., 2002).

Despite all these empirical observations and correlations, the solar-CRF-climate link is still missing a *robus*t physical formulation. It is for this reason that such a link is often understated (IPCC, 2001), but this may change when the advocated experimental tests (Kirkby, 2001) are carried out. The only solar-climate mechanism that presently has a robust understanding, is change in the integrated solar luminosity, but the centennial increase in solar constant (~2–4 W m^{-2}: Pang and Yau, 2002; Solanki, 2002) appears to have been insufficient to account for the observed ~0.6 °C temperature increase (IPCC, 2001). An amplifier, such as the cloud/CRF link, is therefore required to account for the discrepancy. Note, however, that a similar, albeit not as large, amplifier is implicit also in the CO_2 alternative, because the centennial temperature rise in these models is due mostly to the potential, and to some extent theoretical, positive water vapor feedback (Pierrehumbert, 2002) coupled with "parameterized" clouds, not to the CO_2 itself.

In view of the above empirical observations, could it be that the celestial forcing is the primary climate driver on most time scales, including the geological ones? The large stadial-interstadial temperature variations of the latest 420,000 yr, which in the ice cores correlate with ~80 ppm variations in atmospheric CO_2 (Petit et al., 1999), appear to argue against such an alternative. One should note, however, that it is not clear whether the CO_2 is the driver or is being driven by climate change, particularly since the CO_2 appears to lag by centuries behind the temperature changes (Petit et al., 1999; Fischer et al., 1999; Mudelsee, 2001; Monnin et al., 2001; Caillon et al., 2003; Clarke, 2003), thus potentially acting as an amplifier but not as a driver. Can the geological record shed more light on this conundrum?

Unlike the past century, where solar activity, atmospheric CO_2, and global temperatures were predominantly increasing, and unlike the ice cores with their unresolved cause and effect relationship of CO_2 and climate, the situation over the Phanerozoic is different, with all three variables exhibiting a non-monotonic behavior. This may enable decomposition of the global temperature changes into contributions from CO_2, CRF, and a residual. It may also help to settle the causative sequence because celestial phenomena cannot be driven by terrestrial forcing. Moreover, the inherent time scales required for the global climate system to reach equilibrium can be as large as several millennia, owing to the slow heat exchange between the oceans and the atmosphere, and to the slow ice sheet adjustment time. Thus, by estimating the effects of CO_2 over geological time scales, we may obtain the long-term "equilibrium" response of the global climate system.

Recently, Fields and Ellis (1999) and

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[1]The oxygen isotope record is based on ~4500 measurements of shells (brachiopods, belemnites, foraminifera) composed of low-Mg calcite, the carbonate phase most resistant to post-depositional overprint of the signal. The data show a secular ^{18}O depletion trend with age, with superimposed higher order oscillations and it is these that are in phase with reconstructions of the Phanerozoic climate. The major features of these oscillations represent a robust signal in and of themselves, which would be reproduced even if only a fraction of the samples, those near the upper envelope of the secular trend, were taken into consideration. It is this detrended oscillating pattern, with correction scaled for ice volume effect, that yields the Phanerozoic ΔT[°C] variations for contemporaneous low-latitude shallow sea water in Figure 2.

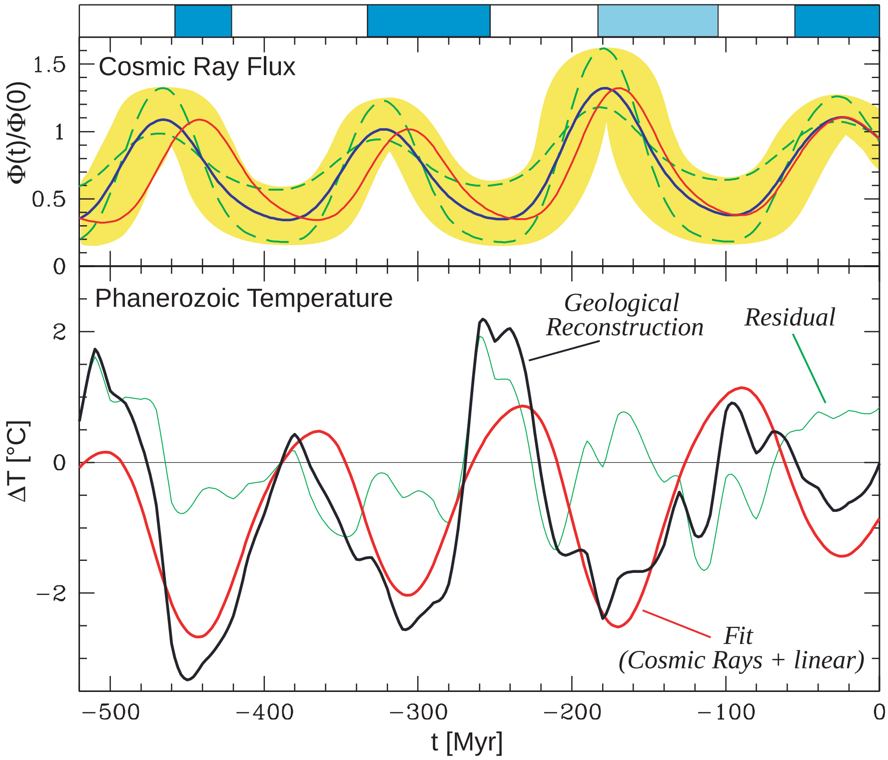

Figure 2. The cosmic ray flux (Φ) and tropical temperature anomaly (ΔT) variations over the Phanerozoic. The upper curves describe the reconstructed CRF using iron meteorite exposure age data (Shaviv, 2002b). The blue line depicts the nominal CRF, while the yellow shading delineates the allowed error range. The two dashed curves are additional CRF reconstructions that fit within the acceptable range (together with the blue line, these three curves denote the three CRF reconstructions used in the model simulations). The red curve describes the nominal CRF reconstruction after its period was fine tuned to best fit the low-latitude temperature anomaly (i.e., it is the "blue" reconstruction, after the exact CRF periodicity was fine tuned, within the CRF reconstruction error). The bottom black curve depicts the 10/50 m.y. (see Fig. 1) smoothed temperature anomaly (ΔT) from Veizer et al. (2000). The red line is the predicted ΔT_{model} for the red curve above, taking into account also the secular long-term linear contribution (term $B \times t$ in equation 1). The green line is the residual. The largest residual is at 250 m.y. B.P., where only a few measurements of $\delta^{18}O$ exist due to the dearth of fossils subsequent to the largest extinction event in Earth history. The top blue bars are as in Figure 1.

Shaviv (2002a, 2002b) proposed that the CRF reaching the planet has not only an *extrinsic* variability due to its attenuation by solar wind, but also an *intrinsic* one arising from a variable interstellar environment. For example, a nearby supernova could bathe the solar system with a higher CRF for many millennia, leave a detectable ^{60}Fe imprint in ocean-floor deposits, and perhaps even give rise to a "cosmic ray winter" (Fields and Ellis, 1999) due to increased cloudiness and planetary albedo. Shaviv (2002a, 2002b) proposed that a particularly large CRF variability should arise from passages of the solar system through the Milky Way's spiral arms that harbor most of the star formation activity. Such passages recur at ~143 ± 10 m.y. intervals, similar to the 135 ± 9 m.y. recurrence of the paleoclimate data (Veizer et al., 2000). Unlike the extrinsic solar-induced CRF modulations, which change the ionization rate at the bottom of the troposphere by typically <10%, the galactic flux variations are much larger and are expected to be about an order of magnitude more effective. It is these intrinsic CRF variations that may be responsible for the long-term climate changes over the past 1 Ga. Specifically, the "icehouses" and the oxygen isotope cold intervals (Fig. 1) appear to coincide with times of high CRF (Fig. 2), as deconvolved from galactic diffusion models and exposure ages in iron meteorites (Shaviv, 2002a, 2002b). The shorter-term annual to multi-millennial climatic effects, superimposed on this long-term baseline, would then reflect the extrinsic modulations of the CRF due to variable solar activity. Changes in orbital parameters and in solar and terrestrial magnetic fields may also potentially modulate this superimposed CRF-solar impact.

CORRELATION OF THE CRF AND PALEOTEMPERATURE DATA

In order to estimate the intrinsic CRF reaching Earth, we used a diffusion model that takes into account the geometry and dynamics of the spiral arms, and considers that cosmic rays are generated preferentially in these arms. We chose three sets of diffusion model parameters (Fig. 2)[2], which span the entire range of CRF histories that are consistent with observational constraints, the latter limiting the period of CRF oscillations to P_0 = 143 ± 10 m.y. (Shaviv, 2002a, 2002b). Because the statistical record of exposure ages for iron meteorites has Poisson noise, the CRF histories we used are not directly extracted from it but they are the smoothed output of the galactic diffusion models constrained to fit the meteoritic record (see Shaviv 2002b for further caveats).

We model the temperature anomaly using the generalized form of:

$$\Delta T_{model} = A + B \times t + C \times f(pCO_2(t)) + D \times g(\Phi(t,P_0)) \qquad (1)$$

where A, B, C, D, P_0 are normalization parameters used to fit the observed ΔT_i.

The constant A normalizes for the average ΔT while the term $B \times t$ describes a linear temporal trend in ΔT. A term of this form is expected due to the increasing solar luminosity during the Phanerozoic, but may also arise from a possible secular variation in the CRF reaching the solar system; for example, from a changing star formation rate. A contribution to this term may also arise from systematic errors in the detrending procedure of the $\delta^{18}O$ data. The third term considers the possibility that CO_2 variations affect ΔT, but at this stage we assume that the term is zero and defer its discussion to subsequent text. The fourth term arises

[2]The observational constraints (for P_0 = 143 ± 10 m.y.) include the cosmic ray ^{10}Be age, and limits on CRF variations derived from iron meteorites. The three models that we utilize (Fig. 2) have a constant cosmic ray diffusion coefficient of $D_{1,2,3}$ = 0.1, 0.3, 1 × 10^{28} cm^2/sec, and a galactic scale height of $l_{1,2,3}$ = 0.5, 0.8, and 1.5 kpc, respectively.

TABLE 1: RESULTS FOR THE MINIMIZATION OF THE VARIANCE BETWEEN MODEL AND RECONSTRUCTED ΔT.

Model no.	CRF model*	CO_2 model†	Parameters minimizing σ^2 §					σ_{min}^2 ¶ $[(°C)^2]$	σ_{18min}^2 ** $[(°C)^2]$
			A [°C]	B [°C]	C [°C]	D [°C]	P_0 [Myr]		
1	–	–	−0.68	–	–	–	–	96.3	18.5
2	–	–	−0.42	0.49	–	–	–	95.1	16.6
3	–	G	−0.38	0.37	−0.03	–	–	95.0	14.7
4	–	R	0.31	0.36	−0.71	–	–	90.3	14.7
5	–	B	−0.75	0.02	0.11	–	–	100.4	15.3
6	(2)	–	−1.03	1.54	–	−6.37	136.3	33.5	12.7
7	(2)	G	−0.76	0.69	−0.26	−6.50	136.2	32.1	10.8
8	(2)	B	−0.30	1.15	−0.61	−6.76	136.8	36.7	11.6
9	(1)	R	−0.56	1.17	−0.38	−3.74	135.5	33.0	10.8
10	(2)	R	−0.62	1.45	−0.39	−6.25	136.5	32.1	10.8
11	(3)	R	−0.41	2.06	−0.42	−11.70	134.8	32.1	10.8

*The three CRF models that span the allowed parameter space of galactic diffusion models and are described in the text. Model 1 describes the maximal, while model 3 has the minimal permissible flux variability.

† The three reconstructed pCO_2 used are those of the GEOCARB III (G), Rothman (R) and Berner and Streif (B).

§ The fit parameters C and D respectively describe the model ΔT obtained for doubling pCO_2 (relative to 280 ppm) and the temperature obtained when $\Phi(t)/\Phi_0$ increases from 0 to 1. P_0 is defined as the average spiral arm crossing period in the CRF model. Since the error on C is larger than the calculated values, these small values, whether positive or negative, are essentially meaningless.

¶ The number of variables is 53 (over the range 520 – 0 m.y. B.P.), for models with the GEOCARB III and Rothman CO_2 reconstructions, and also models without CO_2 reconstruction, while it is 57 (560 – 0 m.y. B.P.) variables for models with the Berner and Streif reconstruction. σ_{min}^2 for models without CO_2 reconstruction with 57 free variables is 100.6, for both models 1 and 2. The number of fit parameters varies between 1 and 5 according to the model.

**σ_{18min}^2 is the minimum residual variance expected due to the measurement variance in the $\delta^{18}O$ data alone (while considering the number of free parameters in the fit). This is the residual expected if we had a perfect theoretical model.

from the variable CRF Φ, where $g(\Phi)$ describes the functional dependence between ΔT and Φ, and D is the actual normalization.[3]

All data (temperature, CRF, and the CO_2 discussed later) are binned into 10 m.y. intervals and averaged using a 50 m.y. window running average. This is because the temporal resolution of the isotope databases and the derivative pCO_2 models are in the 10^6 yr range, while that of the CRF is in the 10^7 yr range. Although Shaviv (2002a, 2002b) discussed the secular variations in CRF for the entire planetary history, the complementary $\delta^{18}O$ record is available only for the Phanerozoic. We therefore truncate our comparison at 520 m.y. B.P. (560 m.y. for the Berner and Streif reconstruction). This gives us N_{meas} = 53 (57) correlated ΔT_i and their corresponding predicted $\Delta T_{model}(t_i)$. Utilizing the three limiting models of CRF variations (Fig. 2), we tested our models by minimizing the residual variance between the model $\Delta T_{model}(t_i)$ and the observed ΔT_i. We find that models that include solely the terms A and B result in a large σ_{min}^2 of $95(°C)^2$. However, once the term D, the CRF normalization, is included, the σ_{min}^2 reduces to $32–36(°C)^2$, in accord with the remarkable inverse correlation of CRF with the paleotemperature (Fig. 2). The CRF alone can explain ~66% of the total variance in the temperature data. Can we further constrain the uncertainties in these models?

The only error on which we have a good handle is the statistical variance arising from the experimental $\delta^{18}O$ data of Veizer et al. (1999). From the internal variance of the $\delta^{18}O$ data within the bins, we can calculate σ_{min}^2 expected from this source of error.[4] This would be the minimum residual statistically attainable if we had perfect knowledge of all sources of climatic factors, exact CRF history, and no other error. This minimum variance, $\sigma^{18}{}_{min}{}^2$, is found to be about $12(°C)^2$ for models including the CRF. Thus, once we introduce CRF as a driver and remove the intrinsic $\delta^{18}O$ measurement variance, we can explain 75% of the paleotemperature variability.

In addition to the $\delta^{18}O$ measurement errors, additional errors may arise, for example, from translation of the $\delta^{18}O$ data into ΔTs that required assumptions on the ice sheet volumes (Veizer et al., 2000), from an inaccurate CRF (e.g., inaccurate knowledge of spiral arm width, amplitude, and exact phase), or from additional factors that may affect the climate (e.g., CO_2, continental geography, oceanic circulation). The magnitude of such a "compound error" and its statistics can be estimated by the bootstrap method.[5] Using this method, we can rule out a fluke correlation between the CRF and temperature at the 99.5% level. That is, *we can*

[3] $g(\Phi)$ is defined such that $g(\Phi) = 0, 1$ for $\Phi(t) = 0, \Phi(\text{today})$ respectively. $\Phi(t,P_0)$ itself is one of the three CRF histories used (Fig. 2). Since theoretical estimates give a power 1/2 relation between ionization rate and CCN density (Dickenson, 1975; Yu, 2002), we use the functional form of $g(x) = x^{1/2}–1$. We also considered other powers, but found the results to change only marginally.

[4] $\sigma_{min}^2 \equiv \sum_i (\Delta T_i - \Delta T_{model}(t_i))^2$.

[5] If we had a perfect model and knowledge of the errors, then the χ^2 of the fit should, on average, be the number of actual degrees of freedom. We therefore add errors quadratically to increase the error in the data until the modified χ^2 per degree of freedom is 1. If we further assume that the unknown measurement and model errors have a Gaussian distribution, we can estimate the errors in the fit parameters. To check the assumption of Gaussianity, we look at the distribution of the residual differences between the model and the best fit (model 6 in Table 1), and find that it is consistent with being Gaussian. (We expect 16.5 points larger than 1 "modified" σ, and find 15, expect 6.9 above 1.7 modified σ and find 4, and expect 2.4 above 2σ and find 3).

rule out with a high confidence level models that do not include the effects of a variable CRF. This conclusion rests on the reasonable assumption that at least one of the two "celestial" data sets with the apparent ~150 m.y. periodicity, the galactic spiral arm analyses or the iron meteorites exposure ages, is valid. While the above correlations are unlikely to be statistical flukes, we do emphasize that the data sets come with some caveats (see Shaviv, 2002b). For example, although the variable meteoritic CRF signal is statistically significant, it could still be generated in 1.2% of random realizations. In another example, it appears that actually *two* spiral arm pattern speeds emerge from various astronomical analyses. While the number that fits the geological and meteoritic data is supported by a strong theoretical argument (Shaviv, 2002b), the meaning of the second number is not yet resolved. Both numbers may be real, however, their meaning hinges on astrophysical considerations that are beyond the scope of this paper.[6]

Armed with the above statistics, we can then place quantitative limits on the CRF-climate connection. We tested 11 models (see Table 1), varying each variable, to find the range of values that gives reasonable fits at the 68% confidence level. The normalization parameter D for all these models varied between 3 and 12 °C. Almost all the error in D arises because we have no good limit on the amplitude of the variation of the CRF itself, except for the lower limit of 2.5 for its maximum/minimum ratio (Shaviv, 2002b). We also find an average spiral arm passage period of P_0 = 137 ± 4 m.y., or 137 ± 7 m.y. if we consider the "jitter" from the epicyclic motion of the solar system (i.e., the noncircular motion around the Milky Way). This is consistent with the meteoritic data showing a periodicity of 143 ± 10 m.y. and the paleoclimate and paleotemperature data with a recurrence at ~135 ± 9 m.y. To further check for consistency, we artificially add a lag to the predicted CRF. We find that the best lag is –3 ± 18 m.y. This implies that the results are consistent with our CRF diffusion model and astronomical data on the spiral arm location. They are only marginally consistent with other possible galactic models, which predict (Shaviv, 2002b) that the actual spiral arm crossing took place ~30 m.y. before the midpoint of the high CRF-climate episode. If we include an independent analysis of the lag in the correlation between the spiral arm passages and apexes of icehouses (Shaviv, 2002b), we can exclude these alternative models at the 98% confidence level.

THE MODEL IMPACT OF CO_2

Realizing that the pCO_2 reconstructions are internally inconsistent, the conservative point of view is to assume at the outset that the entire residual variance that is not explained by the measurement error is due to pCO_2 variations. From the model fit, we find that the temperature variance[7] $\sigma_{T(CO_2)}^2$ attributable to such a "pCO_2" is at most (0.62°C)². To further quantify the effect of "pCO_2," we need to know its variance. Considering that we are not aware of any mechanisms that would stabilize the Phanerozoic pCO_2 at today's values, particularly in view of the large sources and sinks, we assume that these variations span the entire range of the existing pCO_2 models (Fig. 1). With variations of this magnitude, the doubling of CO_2 can account for about $(\sigma_{T(CO_2)}^2/\sigma_{ln(pCO_2)}^2)^{1/2} ln(2) \sim 0.5$°C. A higher impact could be possible only if it is assumed that the Phanerozoic pCO_2 oscillations were limited to values close to the present-day levels.

It is entirely possible that none of the reconstructed Phanerozoic pCO_2 curves (Fig. 1) is a true representation of reality. Nonetheless, we also tested eight scenarios that assume that one of the reconstructed Phanerozoic pCO_2 trends (Fig. 1) is validated. To do this, we reintroduced the third term into equation 1 and considered the impact on temperature by a combined CRF and CO_2 forcing.[8] We find that, depending on the model, the introduction of CO_2 as a driver reduces the σ_{min}^2 [≥32.1(°C)²] by only 0.5–1.5(°C)², compared to 0.2–5(°C)² for models that do not include CRF as a driver. That is, there is no statistically significant correlation between pCO_2 and reconstructed temperature, and we cannot therefore estimate the actual driving impact of CO_2. We can, however, estimate the upper bounds of model uncertainty in terms of temperature that, potentially, could be attributable to CO_2 forcing. This we can do by looking at the errors on the parameter C. Such formal 90% confidence limits are 0.91, 0.92, and 1.14 °C for the Berner and Streif, GEOCARB III, and Rothman reconstructions, respectively. At the 99% confidence limit they are 1.67, 1.46, and 1.93 °C (Table 2). In summary, we find that with none of the CO_2 reconstructions can the doubling effect of CO_2 on *low-latitude* sea temperatures be larger than ~1.9 °C, with the expected value being closer to 0.5 °C. These results differ somewhat from the predictions of the general circulation models (GCMs) (IPCC, 2001), which typically imply a CO_2 doubling effect of ~1.5–5.5 °C global warming, but they are consistent with alternative lower estimates of 0.6–1.6 °C (Lindzen, 1997).

As a qualifier, one should note that global temperature changes should exceed the tropical ones because the largest

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[6]Although the astronomical data points to two possible spiral arm pattern speeds, a theoretical argument based on the observed outer extent of the galactic spiral arm and the spiral arm density wave theory can be made (Shaviv, 2002b). This theory, which nicely explains the spiral arm behavior in non-flocculent spiral galaxies (e.g., Binney and Tremaine, 1987), can be used to show that the observed four-armed spiral structure extending to about twice our galacto-centric radius is only consistent with a narrow range of values, including the spiral arm pattern speed which fits the meteoritic and geological data. The same argumentation can be used to show that the four-armed structure cannot extend significantly inward from our galactic radius. Since spiral arms are apparent also within our radius, they should be either two-armed, have a different spiral arm pattern speed, or both. This could naturally explain the "bimodality" in the astronomical measurements of the pattern speed. It is yet to be explained why the second number is not seen in either the meteoritic or geological data.

[7] $\sigma_{T(CO_2)}^2 = (\sigma_{min}^2 - \sigma_{18min}^2)/N_{meas} = (0.62\ °C)^2$.

[8] In order to calculate the impact of combined CRF and CO_2 forcing we used the functional form $f = 1.236\ [ln(c + 0.0005c^2) - ln(c_0 + 0.0005c_0^2)]$ to which the radiative driving is expected to be proportional (Hansen et al., 1998). The cs are the reconstructed CO_2 histories in ppm, with c_0 = 280 ppm. The normalization is such that the value of C is the temperature increase associated with a doubled pCO_2. We also considered $f = ln(c/c_0)$ and $f = c - c_0$. The former option yields similar limits on C, while the latter results in more stringent limits.

TABLE 2: UPPER LIMIT ON LOW–LATITUDE SEA SURFACE WARMING CAUSED BY CO_2 DOUBLING.

CO_2 History	Upper limit [°C] (at various confidence levels)*		
	68%	90%	99%
GEOCARB III	0.39	0.92	1.46
Rothman	0.70	1.14	1.93
Berner and Streif	0.07	0.91	1.67
Independent[†]	~0.5		

*The confidence levels assume that the unknown sources of error have a Gaussian distribution. The distribution of residual errors is consistent with this assumption.

[†] The independent result assumes only that all the residual variance (not explained by CRF variability or $\delta^{18}O$ measurement error) is due to pCO_2, and that $\sigma^2(\ln(pCO_2)) \sim O(1)$.

temperature variations are in the high-latitude regions for which we do not have any isotope record. A review of GCMs (IPCC, 2001) shows that the globally averaged warming from CO_2 is expected to be typically 1.5 times larger than that of the tropical temperatures, and our model uncertainty limits should therefore be modified accordingly. Note also that the bootstrapping "compound error" includes, among others, any error associated with the ice volume correction. Taking an unrealistic ultimate scenario that assumes no ice volume correction at all, the amplitude of temperature oscillations in Figure 2 could be almost doubled. While these and similar considerations may help in expanding somewhat the above calculated temperature limits potentially attributable to CO_2, they will not alter the relative importance of the celestial-CO_2 forcings. The model impact of CRF will increase in tandem with that of CO_2 for any change in the amplitude of ΔT. As a final qualification, we emphasize that our conclusion about the dominance of the CRF over climate variability is valid only on multimillion year time scales. At shorter time scales, other climatic factors may play an important role, but note that many authors (see previous references) suggest a decisive role for the celestial driver also on multi-millennial to less than annual time scales.

POTENTIAL IMPLICATIONS

Our approach, based on entirely independent studies from astrophysics and geosciences, yields a surprisingly consistent picture of climate evolution on geological time scales. At a minimum, the results demonstrate that the approach is potentially viable, as is the proposition that celestial phenomena may be important for understanding the vagaries of the planetary climate. Pending further confirmation, one interpretation of the above result could be that the global climate possesses a stabilizing negative feedback. A likely candidate for such a feedback is cloud cover (Lindzen, 1997; Ou, 2001). If so, it would imply that the water cycle is the thermostat of climate dynamics, acting both as a positive (water vapor) and negative (clouds) feedback, with the carbon cycle "piggybacking" on, and being modified by, the water cycle (Nemani et al., 2002; Lovett, 2002; Lee and Veizer, 2003). It is our hope that this study may contribute to our understanding of the complexities of climate dynamics and ultimately to quantification of its response to potential anthropogenic impact.

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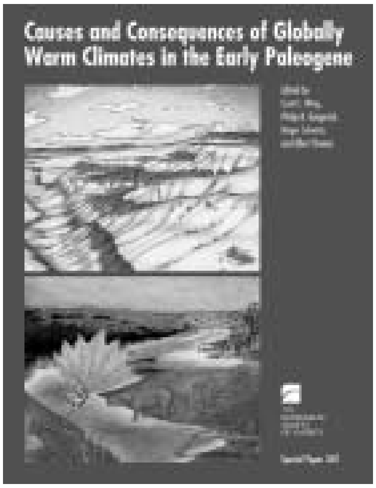

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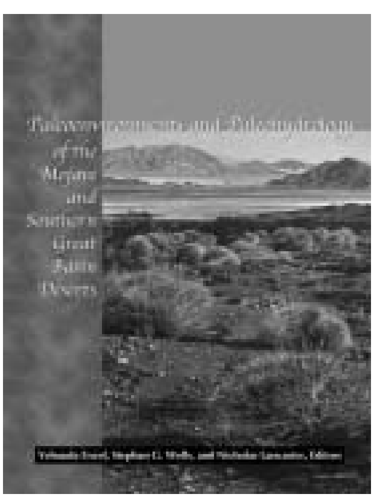

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All courses sponsored by GSA offer CEUs. A CEU is defined as 10 contact hours of participation in an organized continuing education experience under responsible sponsorship, capable direction, and qualified instruction. A contact hour is defined as a typical 60-minute classroom instructional session or its equivalent. Ten instructional hours are required for one CEU. For CEU recordkeeping purposes, please be sure to include your social security number on the online registration form.

1. Applications of Environmental Isotopes for Tracing Anthropogenic Contaminants in Groundwaters and Surface Waters [501]

Sat., Nov. 1, 8 a.m.–5 p.m. Washington State Convention and Trade Center. Cosponsored by *GSA Hydrogeology Division.*

This course will focus on practical applications of environmental isotopes for tracing contaminants in hydrological systems. The systematics of isotope fractionation and the distributions of selected isotopes in natural systems will be discussed briefly. However, the main focus of the class will be on examples of how isotope techniques can be used to determine sources and sinks of nitrate, metals and semi-metals, or organics in surface waters and groundwaters. **Faculty:** Carol Kendall, Water Resources Division, U.S. Geological Survey, Menlo Park, CA; Ph.D., University of Maryland; Tom Bullen, Water Resources Division, U.S. Geological Survey, Menlo Park, CA; Ph.D., University of California, Santa Cruz. Limit: 40. Fee: $550; includes course manual and lunch. CEU: 0.8.

2. DEMs: The Topographic Dimension for Visualizing Geology, Geomorphology, and Active Tectonics [502]

Sat., Nov. 1, 8 a.m.–5 p.m. University of Washington. Cosponsored by *GSA Geoscience Education Division; GSA Structural Geology and Tectonics Division.*

This course familiarizes participants with detailed digital topography for education and research. Topics include DEM properties, evaluating topography, DEM tools, and comparison of coextensive data sets. The course highlights (1) detailed lidar topography for mapping fault scarps, marine terraces, landslides, and geomorphology; and (2) draping maps, satellite imagery, and aerial photography over DEMs to visualize the results in 3D. **Faculty:** Peter L. Guth, U.S. Naval Academy, Annapolis, MD; Ph.D., Massachusetts Institute of Technology; Ralph Haugerud, U.S. Geological Survey, Seattle, WA; Ph.D., University of Washington; Stephen J. Reynolds, Arizona State University; Ph.D., University of Arizona; Paul Morin, University of Minnesota, National Center for Earth-surface Dynamics. Limit: 30. Fee: $650; includes course manual, CD, and lunch. CEU: 0.8.

3. Managing Environmental Projects [503]

Sat., Nov. 1, 8 a.m.–5 p.m. Washington State Convention and Trade Center. Cosponsored by *GSA Engineering Geology Division.*

This course will present an overview of all aspects of environmental project management. We will cover applicable federal and state environmental laws and regulations and discuss how they are applied to ensure regulatory compliance and protection of human health and the environment. The science of project management, including applications of chemistry, biology, toxicology, geology, and hydrology, will be presented. We will also discuss in detail pollution prevention, emergency preparedness, health and safety issues, regulatory permitting, risk assessments, sampling and monitoring protocols, remediation options, professional liability and ethics, and project management skills. An optional exam will be offered following the course for those interested in Registered Environmental Management (REM) certification through the National Registry of Environmental Professionals (NREP). Contact the instructor for more information about the NREP test and certification. **Faculty:** Raymond C. Kimbrough, P.E. LaMoreaux & Associates, Inc., Tuscaloosa, Alabama; B.A., University of Alabama. Limit: 30. Fee: $500; includes course manual and lunch. CEU: 0.8.

4. New Satellite Data and Processing [504]

Sat., Nov. 1, 8 a.m.–5 p.m. Washington State Convention and Trade Center. Cosponsored by *GSA Quaternary Geology* and *Geomorphology Division.*

This short course is an introduction to new satellite data sets and interactive computer processing techniques useful to the field geologist for mapping and analyses. The course will describe the characteristics of new visible–near IR, thermal IR, radar, and digital topographic data sets. Processing techniques will focus on interactive image processing using desktop workstations and inexpensive software. **Faculty:** Tom G. Farr, Jet Propulsion Lab, Pasadena, CA; Ph.D., University of Washington; John C. Dohrenwend, Southwest Satellite Imaging, Teasdale, UT; Ph.D., Stanford University. Limit: 50. Fee: $525; includes course manual and lunch. CEU: 0.8.

Call for Geological Papers:
2004 GSA Section Meetings

South-Central Section
March 15–16, 2004
Texas A&M University, College Station, Texas
Abstract deadline: December 16, 2003
Information: Christopher Mathewson, Texas A&M University, Department of Geology & Geophysics, 3115 TAMU, College Station, TX 77843-3115, (979) 845-2488, mathewson@geo.tamu.edu

Northeastern–Southeastern Sections Joint Meeting
March 25–27, 2004
Hilton McLean Tyson's Corner, Washington, D.C.
Abstract deadline: December 16, 2003
Information: George Stephens, George Washington University, Department of Earth & Environmental Sciences, 2029 G St., NW, Washington, D.C. 20052-0001, (202) 994-6189, geoice@gwu.edu; Rick Diecchio, George Mason University, Department of Environmental Science & Policy, MS 572, 4400 University Dr., Fairfax, VA 22030-4444, (703) 993-1208, rdiecchi@gmu.edu

North-Central Section
April 1–2, 2004
Millennium Hotel, St. Louis, Missouri
Abstract deadline: January 6, 2004
Information: Joachim O. Dorsch, Saint Louis University, Department of Earth & Atmospheric Science, 3507 Laclede Ave., St. Louis, MO 63103-2010, (314) 977-3124, dorsch@eas.slu.edu

Rocky Mountain–Cordilleran Sections Joint Meeting
May 3–5, 2004
Center on the Grove, Boise, Idaho
Abstract deadline: January 27, 2004
Information: C.J. Northrup, Boise State University, Department of Geosciences, 1910 University Dr., Boise, ID 83725, (208) 426-1009, cjnorth@boisestate.edu

2004 GSA Abstracts with Programs

Printed volumes include abstracts for all scientific papers presented at each meeting, plus session programs. Purchase your copies at each 2004 GSA Section Meeting, or order through GSA Publication Sales, 1-888-443-4472, www.geosociety.org. Prices vary by issue.

THE GEOLOGICAL SOCIETY OF AMERICA

Call for Field Trip Proposals
2004 GSA Annual Meeting
November 7–10, 2004 Denver, Colorado

We are interested in proposals for half-day, single-day, and multi-day field trips, beginning or ending in or near Denver and dealing with all aspects of the geosciences.

Due Date for Field Trip Proposals:
October 1, 2003

Please contact the Field Trip Co-chairs:

Eric A. Erslev
Department of Earth Resources
Colorado State University, Fort Collins, CO 80523
(970) 491-5661, fax 970-491-6307
erslev@cnr.colostate.edu

Eric P. Nelson
Department of Geology & Geological Engineering
Colorado School of Mines, Golden, CO 80401-1887
(303) 273-3811, fax 303-273-3859
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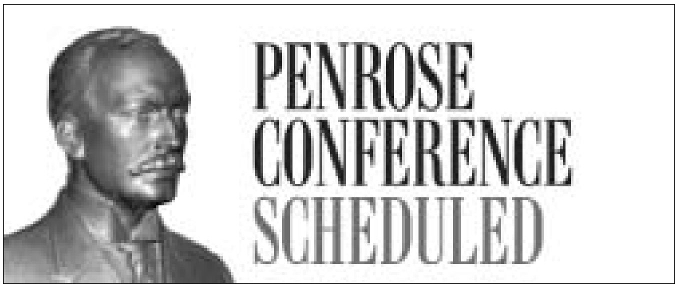

Neogene-Quaternary Continental Margin Volcanism

January 12–16, 2004

Metepec (eastern slopes of Popocatépetl volcano), State of Puebla, Mexico

Conveners:

Gerardo J. Aguirre-Díaz, *Centro de Geociencias, Campus UNAM-Juriquilla, Querétaro, Querétaro, 76230 México; ger@geociencias.unam.mx; 52-5623-4116, ext 107; fax 52-5623-4105*

José Luis Macías, *Instituto de Geofísica, UNAM, Coyoacán 04510, México D.F.; macias@tonatiuh.igeofcu.unam.mx; 52-5622-4124, ext. 19; fax 52-5550-2486*

Claus Siebe, *Instituto de Geofísica, UNAM, Coyoacán 04510, México D.F.; csiebe@tonatiuh.igeofcu.unam.mx; 52-5622-4124, ext. 17; fax 52-5550-2486*

This Penrose Conference will evaluate the present state of knowledge of the source and evolution of magmas that form in a continental-margin volcanic setting. Discussion will include petrology and origin of subduction-related magmas, the complexities of volcanic styles that promote explosive eruptions, sector collapse of volcanoes and domes, volcaniclastic sedimentation, and related volcanic hazards. We'll compare different case scenarios of continental-margin volcanic belts in the Americas, such as the Andes, the Central America Volcanic Arc, the Mexican Volcanic Belt, the Cascades, and the Aleutians. In order to achieve these objectives, we will gather scientists interested in these topics who have enough knowledge and experience to make important contributions during this event. We'll also carry out a 2-day field trip to Popocatépetl active volcano.

The conference is cosponsored by the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). Immediately after this conference, an IAVCEI workshop titled "Neogene-Quaternary continental margin volcanism: The Mexican Volcanic Belt" will be held in the form of a field trip to other locations in the Mexican Volcanic Belt, where discussion of calderas, cinder cone fields, debris avalanche deposits, stratovolcanoes, etc. will continue.

The Penrose Conference includes the following topics:

1. Origin and petrology of continental margin volcanism: examples from the Americas.
2. Petrology of the Mexican Volcanic Belt: a summary of 25 years of continuous research.
3. Chemical composition and physical role of gases associated to continental margin volcanism.
4. Lava domes and block-and-ash flow eruptions.
5. Explosive silicic volcanism and sedimentation processes.
6. Sector collapse, debris avalanches, and lahars.
7. Volcanic risk and hazard mitigation in continental margin volcanic settings.

Field Trip to Popocatépetl

The first day will be dedicated to visiting the base of Popocatépetl volcano summit cone (www.cenapred.unam.mx/UIVR.html) near Paso de Cortés and Tlamacaz mountaineering lodge. Popocatépetl's modern cone consists of andesitic and dacitic lava flows intercalated with pyroclastic deposits. Its crater has an elliptical shape with a major axis of 800 m and a minor axis of 600 m. The major axis is oriented ENE-WSW. The highest crater rim and the summit (5452 m) are located in the WSW, and the lowest crater rim (5250 m) is in the ENE. Popocatépetl's present summit cone is built on the remnants of at least three previously existing edifices.

During the second day we will observe the effects of repeated laharic flooding in the basin of Puebla at the eastern slopes of Iztaccihuatl volcano. During the climactic phases of Popo's past, Plinian eruptions the wind at high altitudes was mostly blowing toward the NE. For this reason large quantities of pyroclastic material were deposited on the NE slope of Popocatépetl as well as

Popocatépetl volcano from the laharic plains near Jantetelco. Photo by C. Siebe.

Popocatépetl from Cholula. In the foreground: Prehispanic pyramid with colonial church on top. Photo by C. Siebe.

on the E slope of Iztaccihuatl. After the eruption this material was quickly removed in the form of rain-lahars which extensively flooded the Puebla basin and destroyed several important settlements such as Cholula, Xochitecatl, and Cacaxtla. We will visit the important archaeological sites of Xochitecatl and Cacaxtla, both of which were abandoned in the 9th century as a result of the devastation of the region by lahars derived from Iztaccihuatl.

The conference is limited to 150 participants. We encourage interested graduate students to apply since some partial subsidies will be available. The registration fee of $480 US will cover lodging, meals, field trip, and all other conference costs, except personal incidentals. Participants will be responsible for transportation from their place of residence to the Mexico City International Airport, where we will meet. At the airport, bus transportation for the participants to the conference place will be available and is included in the cost. Further information on travel will be provided in the letter of invitation but is also available at http://www.turismopuebla.com.mx/.

All participants will be encouraged to present posters on their current research related to the topics of the meeting and significant time will be devoted to view and discuss these.

Cultural Activities

Metepec, and the nearby cities of Atlixco (www.atlixco.gob.mx), Cholula, and the city of Puebla offer a variety of cultural attractions. Cholula is the site of the largest (by volume) pyramid in Mexico (www.tourbymexico.com/puebla/cholula/cholula.htm, www.logicnet.com.mx/~zac450/cholul_e.html). Enjoy a spectacular view of the city of Puebla and several stratovolcanoes from the colonial church constructed atop the pyramid by Spanish conquerors, or visit the many colonial churches and museums in the area. Guided tours to these sites can be arranged prior to or after the meeting.

Application deadline:
September 1, 2003.
Abstract deadline:
September 15, 2003.
Registration payment due:
November 1, 2003.
For detailed information and the application form, visit www.geosociety.org (go to "Penrose Conferences" in "Meetings & Excursions"), or e-mail the conveners. Information can also be found at http://tepetl.igeofcu.unam.mx/penrose/index.html.

GSA EMPLOYMENT SERVICE IS NOW ONLINE!

Job Seekers: Let employers know what you have to offer!

You can now post your profile on the GSA Web site and receive international exposure. Employers looking for candidates that match your qualifications can view your information, and can contact you directly to express interest. You may register at any time throughout the year, and can add to or revise your profile as long as your registration is current. A one-year listing for GSA Members and Associates in good standing is $35; for non-members the cost is $65 (and includes $30 toward membership). To register, go to www.geosociety.org/profdev/ems_app.htm. Let GSA help you find the right job!

Employers: Find the perfect match for your position.

You can save time and resources in your search for qualified employees throughout the year by using GSA's database of job-seeking geoscientists. Complete the Employer's Request for Geoscience Applicants form on the GSA Web site at www.geosociety.org/profdev/ems_emp.htm. Specify educational and professional experience requirements as well as the area or areas of expertise your applicant should have. You will be able to access and print the online profiles of matching candidates, complete with information on areas of specialty, type of employment desired, degrees held, years of professional experience, publications, and current employment status. The cost of access to applicants in one or two geoscience fields is $175. Each additional field selected is $50. Access to the entire applicant database is available for $300. It is solely the employer's decision to contact applicants who interest them; we do not notify applicants of matches. Employers using the matching service are invited, at no additional cost, to have their position announcement posted for three months on the GSA Web site.

Employment Interview Service at the Annual Meeting

If at all possible, take advantage of GSA's Employment Interview Service, which is conducted each fall in conjunction with the Society's Annual Meeting. The onsite service traditionally brings more than 150 applicants together with 40 or so employers for face-to-face interviews. Mark your calendar now for the onsite interview service at the GSA Annual Meeting, in Seattle, Washington. Interviews will be conducted Monday, November 3 through Wednesday, November 5; interview scheduling will start on a first come, first served basis at noon on Sunday, November 2, and will continue through Wednesday.

APPLICANTS: The earlier you register with the service, the more time employers will have to find your profile online. Indicate on your profile that you would like to interview in Seattle. Employers also will have onsite access to your information and profile. Even if you decide to take part at the last minute, you can register with the service onsite and schedule interviews.

EMPLOYERS: When you rent interview space at GSA's Annual Meeting, our staff will schedule interviews for you. Plus, you'll have access to the entire applicant database and profiles, a message center, ongoing posting of job openings, on-site applicant registration and profile updating, and photocopying services. Space is rented in half-day increments. Or you can forego the interview booth, but use all the other services with the Message Center Only option. We offer flexibility and service—it's your choice!

More information and forms are posted in the Employment Opportunities section of www.geosociety.org. Or, contact Nancy Williams, Director of Membership, Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140, (303) 357-1017, or nwilliams@geosociety.org.

THE GEOLOGICAL SOCIETY OF AMERICA

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New GSA Members

The following members were elected by Council action at its May 2003 meeting for the period of October 2002 through February 2003.

Michelle Abraham
Nicos G. Adamides
Matthew D. Affolter
Ramil Surhay Ahmad
David K. Alexander
Dawn A. Alexander
Conrad K. Allen
John A. Allen
Margaret A. Allen
Sandra Allen
Arafat A. AlShuaibi
Armando Altamira
Robert Amerman
Robert Anders
Heather E. Anderson
Mark T. Anderson
Scott R. Anderson
Benjamin J. Andre
Graham D. Andrews
Michael J. Appel
Billie Jo Arnold
Tracy Arsenault
Wasinee Aswasereelert
G. David Atkins
William H. Avery
Dov Avigad
James D. Ayers
Jennifer T. Back
Noelia Baez
Mark Bailey
Sophie E. Baker
Mark Bakker
Amy M. Balanoff
Heather A. Ballantyne
Zsuzsanna Balogh
Deborah C. Banks
David B. Barnett
Amanda D. Barnhart-Slaughter
Miriam Barquero-Molina
Jeff A. Bartlett
Kate E. Barton
Ryan H. Baskin
Wesley J. Baucke
Christian H. Baxter
Brian R. Beck
Harry J. Becker
David W. Beilman
James M. Beke
Jack Bellan
Kevin C. Belt
Nathan M. Bentley
Joan M. Bernhard
Charles W. Betton
Daniel D. Betts
Gabe S. Bever
Carrie A. Beveridge
James A. Bianchin
Marron J. Bingle
Lauren L. Bissey
Cherylee M. Black
Robin S. Black
Joan B. Blainey
Mehgan O. Blair
James L. Blankenship
Karen O. Blount
James G. Bockheim
Robert Bodnar
Matt Boggs
Joshua R. Bolling
Jamie M. Bonisteel
Philip S. Borkow
Kip Bossong
Matthew R. Bourke
Benjamin Boyer
Douglas M. Boyer
John Boylan
Elizabeth K. Brabson
Patrick K. Brand
Katherine A. Brandt
John R. Branom Jr.
Terrance P. Brennan
Bart Bretherton
Daniel S. Brounstein
Dana C. Brown
J.J. Brown
Rusty C. Brown
Dan E. Bulger
Nimeesha Bulsara
Lee Anne Burrough
Richard A. Busch
Jonathan C. Bushey
Amanda M.M. Bustin
Laurie Button
Benjamin N. Bymers
Ana M. Cadena
Michael J. Calaway
Ian Cameron
Joshua S. Campbell
Jennifer J. Cardran
Heather A. Carlos
Michael E. Caron
Deron T. Carter
Judd A. Case
Octavian Catuneanu
Grady H. Caulk
Robinson Cecil
Nurgul Celik Balci
Artemi Cerda
Yeung Suk Cha
Gareth R. Chalmers
Joseph F. Chandler
Catherine E. Channing
Sumantra Chatterjee
Hanlin Chen
Adidi Chenna
Jenny Cosima Cherryhomes
Chukwuemeka Chinaka
Sung-Ja Choi
Wan-Joo Choi
Wei Chu
Ueechan Chwae
Matthew E. Clapham
Eugene E. Clark
Renee M. Clary
David Cole
Gertrude E. Cole
Duff Collins
Candice Constantine
Jennie Cook
Brian E. Corey
Jesse A. Corrow
Margo Cortes
Erica B. Cortez
Sandor R.F. Coscia
Carol J. Cotterill
Rachel D. Couch
Marco A. Coutino Jose
Claire M. Coyne
James G. Crock
Bob Crone
Bruce M. Crowe
Mark D. Cruise
Alejandro Cuevas
Matthew L. Cupper
John B. Czarnecki
Elad Dafny
Arthur R. Dahl Jr.
William L. Dam
Jan Dash
Heather M. Davidson
Michelle M. Davidson
Drew K. Davis
Scott E. Davis
Valerie C. Davis
Dara C. Dawson
Narendra N. De
Michael T. DeAngelis
Sara M. Decherd
Kevin O. DeGrosky
Bob Dennis
Lisa Depoe
Aram N. Derewetzky
Deepu Dethan
Alexander Deutsch
Fionnuala Devine
Terrence J. Dewane
Dalphania S. Dickerson
Kathleen E. Donnelly
Jeff A. Dorale
John N. Dougherty
Marianne S. V. Douglas
Jon C. Dowell
Charlene L. Drake
Sara E. Draucker
Brian Dreyer
Thomas Driesner
Agnes Dubois
Harvey R. Duchene
Mark A. Dudley
Elise J. Dufour
Jon A. Duke
Michael J. Dunlap
Sedelia R. Durand
Arthur S. Dyke
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Kristin A. Ebert
Robert P. Eganhouse
Jonathan B. Ellingson
George W. Ellsworth Jr.
Davide Elmo
Elizabeth K. Erickson
Melinda L. Erickson
Francisco Escandon-Valle
Frank Evans
Helen F. Evans
Stephen G. Evans
Jerry P. Fairley
Mohammad D. Fakhari
Donald W. Fallon
Jessica Fallon
Juraj Farkas
Rick Farrar
Matt C. Farris

Tracy L. Fenger
Eric W. Ferguson
Autumn R. Fernald
Brent C. Ferry
Mary Anne Fillipone
Steve T. Finch
Kayse Fisher
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Colleen J. Fowle
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Jason M. Francis
Robert Daniel Francis
Shaun K. Frape
Chad Freed
James Freiheit
Marcy Jo French
Richard P. Friese
Nicholas J. Fromm
Gary S Fuis
Jose L. Gago
Eric Gaidos
Christopher N. Gale
Josip R. Galetovic
Tara Ganse
Paul J. Garrett
Matthew P. Gatewood
Stephen R. Gearheart
Sanghamitra Ghosh
David M. Gilbert
Lea A. Gilbertson
Shana C. Gillette
Brett H. Gilley
Christopher S. Gilliam
Christine M. Girtain
John A. Glennon
Oguz Gogus
Jessica C. Goin
Andrew R. Gomolak Jr.
Shane A. Goodnight
Daniel P. Gorman
Laurie Beth Gorton
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Jesse C. Grady
Suzanne C. Grandy
Robert G. Grantham
Fabienne M. Grellet-Tinner
Gerald Grellet-Tinner
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Lisa L. Harrell
Lee Harrison
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Leslie E. Hasbargen
Laurie B. Hauptmann
Andrea D. Hawkes
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David H. Huntley
Francois Huot
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Steven J. Ings
Toru Ishikawa
Tatsuya Ishiyama
Mohammed R. Islam
Erkan Istanbulluoglu
David D. Jackson
Joseph R. Jacobs
Kevin L. James
Lorna G. Jaramillo-Nieves
Tim M. Jellett
Robert G. Jenkins
Hugh C. Jenkyns
Junfeng Ji
Lixin Jin
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Marina Manea
Vlad Constantin Manea
Chandrika Manepally
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Jennifer M. Mangan
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Matthew C. Middleton
Matthew C. Mihlbachler
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Bolortsetseg Minjin
Scott C. Mitchell
Arijit Mitra
Katty Mobasher
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Carolyn A. Moeller
Castulo S. Molina
Mike C. Moncur
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Jason R. Moore
W. Richard Moore
Briana E. Mordick
Francisco Moreira Rivera
Elena Moreno-Barbero
Caroline-Emmanuelle Morisset
Kazuyoshi Moriya
Christopher Morris
Neil E. Moss
Sarah E. Mueller
Bimal Mukhopadhyay
Sean R. Mulcahy
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Kim Pearce
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Suzanne A. Pierce
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Linda L. Taylor
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Jennifer Teerlink
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Theodore Tesler
J. Ryan Thipgen
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Hsin-Hsiu Ting
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Tjalle T. Vandergraaf
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Lynette I. Vayo
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Claudia Velez
Jesse C. Vermaire
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Sharon A. Wilson
Charles D. Winker
Russell T. Winn
Ewan D.S. Wolff
Christopher J. Woltemade
Ngai Yuen Wong
Deborah Woodcock
Miriam Woods
Christy A. Woodward
Richard E. Woodward
Marie P. Worley
Khryste M. Wright
Shawn P. Wright
Jennifer M. Wulforst
Thomas C. Wylie
Ancheng Xiao
Huifang Xu
Jie Xu
Shulin Xu
Yukio Yanagisawa
Li Yang
Shufeng Yang
Dennis H. Yankee
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En-Chao Yeh
Kristina D. Yelinek
Mark Yinger
Yeong-Ju Yoo
Dino L. Zack
Alexandre Zagorevski
Khandaker M. Zahid
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Grant D. Zazula
Kathryn G. Zeiler
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New GSA Associates and Affiliates

Affiliates

The following people joined GSA as Affiliates during the period of October 2002 through February 2003.

Russell J. Bak
Joshua A. Calkins
Andrew J. Graff
John K. Hawley
Matt P. Jedynak
Susan Passmore
David L. Semenoff
William L. Spence

Student Associates

The following people joined GSA as Student Associates during the period of October 2002 through February 2003.

Jeremy R. Abbey
Michelle Abriani
David L. Abt
Tarik (Ricky) Abu-Hussein
Kathryn M. Adank
Paul A. Agle
Adekumle S. Aladesulu
Paul B. Albers
Joel G. Allen
Patrick M. Allen
Jonathan D. Alvarez
Terri A. Amborn
Alvin D. Anderson
Daniel J. Anderson
Joseph M. Andrews
Sarah Askey
Steven Aspden
Alexis K. Ault
Tin Maung Aye
Brian Bagley
Amanda S. Bahls
Heather B. Bailey
Wade Bailey
Karina Bailon
Tammy E. Baker
Russell N. Balliet
Mitchell E. Barklage
Bronson J. Barton
Carly E. Bastow
Heather L. Baugh
Jennifer L. Baxter
Lorraine M. Beane
Stephanie Bear
Emily Bellinger
Antony Berthelote
Rachel Betrus
Angela Bice
Susan D. Billow
Jeffery R. Bird
Nathan A. Bishop
Michael J. Blackstone
Jeremy M. Blansett
Kathleen S. Bleach
Heather A. Bleick
David R. Blood
Kevin R. Bogdan

Cherina N. Booker
Miriam N. Borosund
Eleanor S. Boyce
Ira A. Bradford
Reed Brandvik
Billie Anne Brauch
Ethan L. Brown
Tiffany Brown
Sean P. Bryan
Edward R. Brzostek
Devin P. Buick
Debbie A. Bush
R. Michele Buttram
Craig D. Byer
Nelson M. Byrd
Daniel I. Byrne
Jamie M. Cachine
Daniel D. Cadol
Caterina M. Caiazza
Julie A. Calkins
Charlotte L. Campagna
Adam MP Canfield
Stephanie V. Capello
Erin Carroll
Zachary S. Casey
Emily N. Caskey
Christelle C. Castet
Janis Y. Casto
Jay Chapman
Randall Chapman
Phuong K. Chau
Sarah H. Cheesman
Elizabeth J.S. Chesser
Laurel B. Childress
Michael A. Choate
Ana J. Cichowski
Howard Biff Coates
Catherine Coffey
Krista L. Collier
Joanna G. Colvin
Heather P. Cook
Elizabeth Copeland
Catherine E. Corriveau
Christopher Coughenour
Lisa M. Cowley
William H. Craddock
Brian J. Craig
John C. Crawford
Scott A. Crombie
Angela Cross
Adam Z. Csank
R. Brent Cunningham
Gerard P. Czarnecki
Thomas A. Daigle
Barbara A. Dalgish
David R. Daniels
Thomas H. Darby II
Nigel Davies
David A. Davison
Jacob E. Day
David de Give
Joost Maarten de Moor
David A. Dechant
Benjamin D. Dejong
Laura M. DeMott
Stephanie DePoala
Brian E. DesGagnes
Aaron J. DeVries
Sean Dickie
Angela Diefenbach
Theresa M. Diehl
Judith B. Dippy
Brian Dolan
Eric T. Donaldson
Evan Donegan
Vanessa A. Donnelly
Jason E. Duke
Josh C. Dunn
Michelle DuPree
Orland R. Durben
Leonard J. Eakin
Heather Easterly
Erin N. Eastwood
Victoria M. Egerton
Amy E. Eisin
Blake D. Eldridge
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Theresa N. Engel
Kyle J. English
Marty Erwin
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Mary E. Faw
Jonathan J. Felis
Matthew F. Fey
Christopher M. Fisher
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Kathryn S. Flynn
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John M. Glowa
Antonio Godinez
Jeffrey C. Goeden
Evan B. Goldstein
Jennifer J. Goodall
Christopher Goodmaster
Brian P. Goodwin
Mark A. Gorman
Ramey E. Goss

Alison Graettinger
Kristopher J. Graham
Jena Green
David Greene
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Phillip Kast
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Ethan Earl Kerns
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GSA Foundation Update

Donna L. Russell, *Director of Operations*

Education & Outreach Update

Many exciting things are happening in GSA's Education & Outreach Department (E&O) this year:

The GSA Teacher Advocate Program, a new program that will begin in July, will focus on geoscience teaching resources and activities. The program's goal is to promote the geosciences to school students and families through active and enthusiastic teacher advocates. This will be accomplished by:

- Providing up-to-date curriculum–linked geoscience teaching resources to schoolteachers across the U.S. and beyond. The curriculum will be developed by professionals who have had recent classroom teaching experience.
- Providing field activities for teachers so they can experience the importance, relevance, and wonder of geoscience first-hand.

The resources produced for teachers will cover plate tectonics, climate change, paleontology, volcanology, land-forms, earthquakes, and rock and mineral identification. These resources will help teachers make geoscience exciting for their students through the use of activities, images, and models. Based on a similar Australian program, the GSA Teacher Advocate Program has the potential for enormous impact within the U.S.

Teachers will also have the opportunity to experience the wonders of the earth through field activities at some of the most extraordinary geologic locations on Earth. How much better will their teaching be after they have experienced first-hand the mighty work of a glacier or the sight, smell, and sound of a volcanic eruption? Promoting teacher enthusiasm for the geosciences is the whole key to this program.

GeoCorps America continues to make a difference for young geoscientists by involving them in projects in our national parks and forests, where they also have the opportunity to interact with park visitors. We've received 350 applications for this year's 36 summer positions; the success of this program has been enhanced by the high-quality applicants who are chosen to participate. Both Shell Oil Company and the American Geological Institute have recently made contributions to the future of young scientists by donating to GeoCorps.

Support for E&O

Support for these two programs is vital. If you would like to donate to GeoCorps America or the GSA Teacher Advocate Program, please check the coupon below and return it to the GSA Foundation. You can also donate online at www.geosociety.org/gsaf.

Most memorable early geologic experience

As a child during World War II, I tasted water bailed from an oil well, found it salty, and thought there had to be an ocean down there. I've been looking for ancient oceans ever since.

—Don Woodrow

Coming of Age in the 21st Century

GSA Foundation

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Boulder, CO 80301-9140 • (303) 357-1054
drussell@geosociety.org

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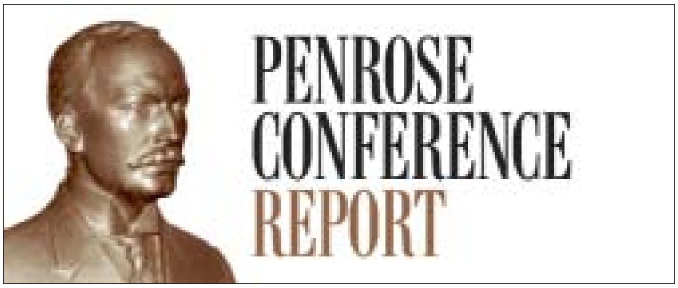


Three-Dimensional Flow, Fabric Development, and Strain in Deformed Rocks and the Significance for Mountain Building Processes: NEW APPROACHES

August 18–24, 2002

Conveners:

Hermann Lebit, *Department of Geology, Georgia State University, 340 Kell Hall, Atlanta, Georgia 30303, USA;* ***Catalina Lüneburg,*** *Department of Geoscience, State University of West Georgia, Carrollton, Georgia 30118, USA;* ***Peter Hudleston****, Department of Geology and Geophysics, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, Minnesota 55455, USA; and* ***John Ramsay****, Cratoule-Issirac, F-30760 St. Julien de Peyrolas, France*

The conference was held August 18–24 at Monte Verita, a conference center of the Swiss Federal Institute of Technology (ETH) situated on a steep hillside overlooking the town of Ascona and Lago Maggiore in the canton of Ticino. This venue was ideally suited for field excursions into the central Penninic nappes and the plate collision zone of the Ivrea-Verbana region. It also allowed participants excellent views of the southern Swiss Alps during the meeting. The 77 participants were a diverse group in age and experience as well as geography: 35 from the United States, eight from Switzerland, eight from Germany, six from Britain, four from Australia, three from Spain, two each from Canada, India, and France, and one each from Bulgaria, Cameroon, Finland, Israel, New Zealand, Norway, and Portugal. Sixteen of the participants were graduate students and five were postdoctoral researchers.

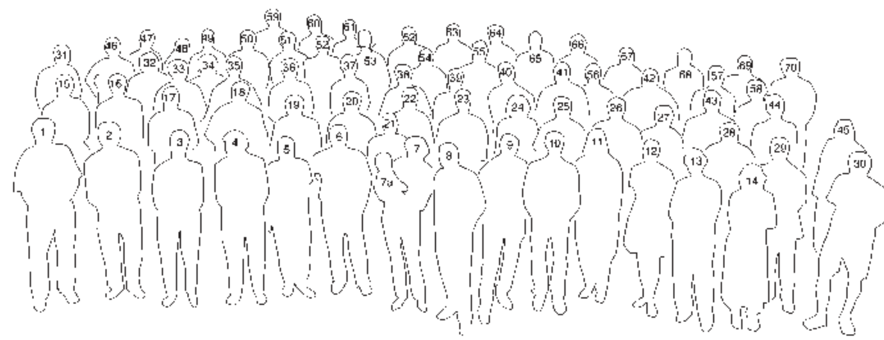
The conference theme was the geometry and mechanics of three-dimensional deformation and crustal tectonics, with insights and contributions coming from applications of the many new techniques and scientific developments that have occurred over the past decade. Various approaches were taken, including field analysis, laboratory experimentation, physical modeling, and computer modeling during several days of presentations and discussion at the Monte Verita Centre interspersed with three days of field excursions in regions particularly relevant to the topic of the conference. The days in Monte Verita were organized around a series of keynote presentations followed by extensive open discussion. The discussion periods were especially productive, allowing everyone a chance to express opinions, ask questions, and challenge one another. The discussion time stimulated wide-ranging, free, and sometimes heated exchanges among audience members and with the speakers. Many participants brought excellent posters; these also were the focus of much informative discussion.

Principal Topics

Strain and what we can do with it. Keynote speakers: John Ramsay, Sudipta Sengupta, Declan DePaor, John Watkinson, Renee Heilbronner, Ernest Rutter, Bernd Leiss, and Basil Tikoff. The first presentations focused on modeling superposed fold systems, with special reference to the complex three-dimensional geometry and strain states that can arise. This led to a general analysis of stress and strain and the complex mechanics of the folding of inclined layers in three dimensions. Methods of examining cumulative and evolutionary fabrics, both in natural and experimentally deformed rocks—especially those produced using experimental torsion techniques—were shown to have great geological implications. The final presentation involved discussion of how mantle geometry, deduced from an analysis of seismic shear wave splitting, might be related to the structures in the lower crust.

Models and kinematic indicators: What they really tell us. Keynote speakers: Peter Hudleston, Arthur Snoke, Jordi Carreras, John Dewey, Cees Passchier, Carol Simpson, Rick Law, and John Wheeler. Most of these presentations concentrated on the development of shear zones and shear sense indicators found in and around shear zones. Many shear zones show complex non-plane strains, and speakers showed how these may arise and how strain compatibility may be maintained. Specific applications varied widely from small-scale to regional tectonic features, and a wealth of excellent field data was presented. The regional implications of transpression and transtension were shown to be important in many tectonic zones. Presentations of the results of recent physical and numerical modeling experiments were of particular relevance to field investigations. The last speakers showed how the information these provide might be used to understand the significance of large-scale regional features in the Alps and Himalayas.

Reconstructing regional deformation histories by modeling or by outcrop analysis. Keynote speakers: Richard Lisle, Alison Ord, Djordje Grujic, Jean-Pierre Burg, James Jackson, Ray Fletcher, and Martin Burkhard. The day began with a novel reinvestigation of the methods that can be used to describe the three-dimensional geometry of many types of folds, both single- and multiple-phase. Pressure solution was the subject of some stimulating new computer modeling done by Australian researchers. Larger-scale general tectonic modeling and specific modeling of Himalayan and Alpine tectonic features showed how approaches based on a geometric analysis of final-state geometry can be used to develop plausible developmental models for such features. The recent use of satellite positioning techniques in currently active tectonic zones in Greece and western North America showed how an analysis of recent deformations can greatly assist an understanding of large finite displacements and strains. It was clear that field geologists can benefit from the insights of those using modeling methods, but that modeling must still be based on accurate and judiciously collected field data.



Conference participants. Numbers following names refer to position in photo (by row from front to back, left to right); participants not present in the photo are identified with an asterisk: Jeff Amato (10), Chuck Bailey (39), Michael Bestmann (21), Shamik Bose (16), Mark Brandon (18), Margaret Brewer (*), Jean-Pierre Burg (67), Martin Burkhard (29), Luigi Burlini (*), Noel Canto-Toimil (36), Jordi Carreras (20), Dyanna Czeck (45), Jean Crespi (12), Hagen Deckert (52), Declan DePaor (44), Allen Dennis (57), John Dewey (*), Dorthee Dietrich (5), David Durney (33), Mike Edwards (53), Carol Evenchick (*), Paul Evans (30), Raymond Fletcher (15), Klaus Gessner (*), Art Goldstein (69), Albert Griera (38), Djodje Grujic (46), Tekla Harms (13), Robert Hatcher (62), Reneé Heilbronner (3), Christoph Hilgers (61), Christopher Holms (26), Eric Horsman (*), David Hood (9), Peter Hudleston (55), Zeshan Ismat (24), James Jackson (59), Richard Jones (68), Paul Karabinos (43), Richard Ketcham (40), Sergio Llana-Funez (51), Richard Law (70), Hermann Lebit (8), Bernd Leiss (65), Richard Lisle (63), Catalina Lüneburg (7) and Adrian (7a), Neil Mancktelow (27), Micheal Maxelon (37), Gautam Mitra (25), Alison Ord (58), Fernado Ornelas (49), Cees Passchier (*), Terry Pavlis (17), Jeffrey Rahl (22), John Ramsay (4), Ernest Rutter (1), Stefan Schmalholz (50), Stefan Schmid (31), Sudipta Sengupta (14), Carol Simpson (34), Arthur Snoke (54), Gary Solar (42), Aaron Stallard (60), Aviva Susman (48), Jean Pierre Tschouankoue (6), Michael Terry (56), Basil Tikoff (32), Jens Walter (66), John Watkinson (2), Matthias Weger (28), Rami Weinberger (47), John Wheeler (35), Robert Wintch (41), Christine Witkowski (11), Steven Wojtal (23), Adolph Yonkee (64), and Ivan Zagorchev (19).

Field Trips

In a special evening lecture, Stefan Schmid provided an excellent introduction to the three days of excursions, summarizing the regional geology of Switzerland and current thinking on the architecture and tectonics of the Alps. A highlight of his talk was a very new interpretation of seismic data obtained by the Transalp project, which transects the eastern Alps close to the Brenner Pass. In contrast to a similar project in the western Alps that identified a southward-dipping lithospheric slap, the transect in the eastern Alps seems to indicate two oppositely dipping slaps. The south-dipping one may be the continuation of that seen in the western Alps, whereas the north-dipping one may correspond with the Dinaride system.

The Laghetti shear zones of Maggia Nappe of the Central Alps. Conference participants saw, crawled over, and photographed classic examples of shear zones developed during the Alpine deformation of pre-Alpine basement granitic and dioritic rocks. The complex geometry of and interconnections of shear zones are apparent in these examples.

Structures in the main nappe flat zone and steeply dipping "root zone" of the Penninic region. Well-exposed complex folding of crystalline basement and Mesozoic marbles was studied in the walls of the Verzasca hydroelectric dam. Later, the group investigated the spectacular basement outcrops at Lavertezzo in Val Verzasca, where the gneissic banding shows geometrical forms characteristic of superposed folds. These folds are cut by late Alpine aplite and pegmatite dykes.

Ductile mylonitic structures in the Alpine root zone and in the Ivrea-Verbano zone. Complex folding of pegmatite veins in the Monte Rosa root zone north of Arcegno shows that deformation was proceeding as Alpine pegmatites were being intruded into the basement gneisses. A complex history of ductile deformation, mylonite formation, and semi-brittle and brittle shear zones can be deciphered in the Ivrea-Verbana zone in road sections just west of Monte Verita.

A field guide to these superb outcrops, written by Stefan Schmid, Hermann Lebit, Catalina Lüneburg, John Ramsay, Dorothee Dietrich, and Djordje Grujic, is available. Contact Hermann Lebit, hlebit@westga.edu, for details.

Pre-Conference Trip

Prior to the conference, 25 participants undertook a nine-day excursion transecting the Swiss Alps from the external parts to the orogenic core. The trip started with the Glarus thrust, the classic basal thrust of the Helvetic nappes in Eastern Switzerland. The architecture of the Helvetic nappes and the subalpine Molasse was studied around Lake Lucerne. Moving toward the southwest and more internal zones, attention was then focused on basement-cover relations and reactivation of pre-Alpine structures in the Aiguilles Rouges Massif of Western Switzerland. In the overlying Morcles fold nappe, the group examined structures and strain features that indicate changes in transport direction during nappe emplacement. Moving to the internal zones, multiple phases of Alpine deformation and associated structures and fabrics were studied in the Pennine units of the Central Alps. Excellent exposures of tectonic and sedimentary structures were examined along a section through amphibolite-facies Mesozoic metasediments at Nufenen Pass. Fold interference patterns and complex superposed strains are well exposed in the metamorphic cover rocks of the Lepontine nappes. Outcrops of strongly deformed conglomerates in the Lebendun nappe exposed in the Cristallina area provided a wonderful opportunity for discussing the significance of stretching lineations as kinematic indicators.

The three-dimensional geometry and kinematics of late alpine tectonics were studied at the Simplon normal fault, which is a spectacular example of how pre-existing structures from the contractional phase of deformation became modified during late orogenic extension. Pre-existing structures are overprinted by progressively intense brittle deformation in the hangingwall and ductile deformation in the footwall as the shear zone is approached from either side.

The pre-conference field trip benefited greatly from the support and participation of local experts, and we wish to thank David Durney, Martin Burkhard, Neil Mancktelow, Eva Klaper, and Djordje Grujic for sharing their expertise with the group. John Ramsay, Dorothee Dietrich, Flavio Amselmetti, and other colleagues contributed to the field guide, which was compiled by Hermann Lebit and Catalina Lüneburg.

At the close of the conference, participants expressed strong interest in contributing papers to a special publication based on the theme of the conference. With the approval of GSA, the conveners have made arrangements for papers stemming from the conference to be published in a special issue of the *Journal of Structural Geology*.

Acknowledgments

We are grateful to GSA and the GSA Foundation for sponsoring the meeting as a Penrose Conference. We thank Centro Stefano Franscini at ETH Zürich for professional conference coordination (through the persons of Karin Mellini and Claudia Lafranchi) and we are grateful to ETH for covering fees for the lecture hall and the other facilities at Monte Verita. The Geologisches Institut of ETH, Zürich, generously allowed us to use their facilities for making preparations for the conference and the pre-conference field trip. In all this, Jean Pierre Burg played a key role. The Swiss National Fund is acknowledged for its financial support (SNF 21-68415.02), and the National Science Foundation is acknowledged for a grant to support the attendance of graduate students and young career scientists (EAR 0223797). Finally, we thank the participants for their individual contributions and enthusiastic involvement in all elements of the conference. ▲

ANNOUNCEMENTS

Meetings Calendar

2003

September 1–4	Sixth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe and the Commonwealth of Independent States (Prague 2003), Prague, Czech Republic. Information: John Moerlins, Institute for International Cooperative Environmental Research, Florida State University, 226 Herb Morgan Building, 2035 East Paul Dirac Drive, Tallahassee, FL 32310-3700, (850) 644-7211, fax 850-574-6704, info@prague2003.fsu.edu, www.prague2002.fsu.edu.
September 24–25	Discover Mongolia 2003: International Mining Conference, Ulaanbaatar, Mongolia. Information: Sado D. Turbat, (976) 11-328461, fax 976-11-313287, mineinfo@mongolnet.mn, www.mram.mn.
December 8–10	From Mallik to the Future—An International Symposium on results from the Mallik 2002 Gas Hydrate Production Research Well, Mackenzie Delta Canada, Chiba (Tokyo area), Japan. Information: Scott Dallimore, Program Chair, GSC-Pacific, 9860 West Saanich Road, Sidney, BC V8L 4B2, Canada, (250) 363-6423, sdallimo@NRCan.gc.ca, www.gashydrate.com. *(Open meeting; presentations limited to Mallik participants.)*

Visit www.geosociety.org/calendar/ for a complete list of upcoming geoscience meetings.

About People

Ellen Bergfeld was named executive vice president to lead three scientific, educational societies headquartered in Madison, Wisconsin: the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America, a GSA Allied Society.

GSA Fellow **Gordon P. Eaton** received a special honor at Iowa State University on April 11, 2003. Eaton, who was president of Iowa State from 1986 to 1990, celebrated the official naming of a new, 86,000 square foot student residence: Gordon P. Eaton Hall. Eaton, a GSA member since 1954, retired as director of the U.S. Geological Survey in 1997, and is a GSA Foundation Trustee.

GSA member **Geoffrey O. Seltzer**, associate professor of geology in the College of Arts and Sciences, was recently honored for being named Alumni Associate Professor at Syracuse University. Syracuse Vice Chancellor and Provost Deborah A. Freund announced the prestigious honor at a campus ceremony March 25.

Student Research Grants in Mathematical Geology

The Student Grants Program of the International Association for Mathematical Geology (IAMG) supports graduate student research in broad areas of mathematical geology for the purposes of advancing the development and application of quantitative methods in the geosciences. Recipients of the awards, which typically amount to US$2,000, must be enrolled in a formal university program in which they are pursuing a graduate degree. Complete application information and requirements are posted at www.iamg.org. Written proposals for 2003 funding should be sent to Donna Dennison, Student Grants Committee, IAMG Office, 4 Cataraqui St., Suite 310, Kingston, ON K7K 1Z7, Canada. Submission deadline is July 31, 2003.

GSA Welcomes AMQUA as an Associated Society

At the May GSA Council meeting, the American Quaternary Association (AMQUA) was accepted as a GSA Associated Society. AMQUA's Web site is www.4.nau.edu/amqua, its president is Dan Muhs of the U.S. Geological Survey in Denver, and its secretary is Bonnie Styles of the Illinois State Museum.

Tyler Prize Seeks Nominations

The Tyler Prize for Environmental Achievement is seeking nominations for its 2004 laureate. The Tyler Prize awards $200,000 (joint winners share the cash prize) for exceptional work in one of the following areas: (1) protection, maintenance, improvement, or enhanced understanding of ecology and environment; (2) discovery of new sources of energy, or the further development, improvement, or enhanced understanding of those sources; or (3) medical discoveries or achievements that significantly benefit the environmental aspects of human health worldwide. Nominations should be sent by e-mail to tylerprz@usc.edu and must include: the nominator's name, mailing address, present occupation title and institution title, the nominee's vita or resume, a one-page statement of the nominee's accomplishments, three or more letters of reference (mailed directly to Tyler Prize office, c/o Linda E. Duguay, Executive Director of the Tyler Prize, University of Southern California, 3616 Trousdale Parkway, Suite 209, Los Angeles, California, 90089-0373), and the names and addresses of three to five additional references. For further information, e-mail tylerprz@usc.edu. Nomination deadline: September 15, 2003.

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GSA Bulletin seeks a co-editor beginning July 1, 2004, for a four-year term. A phased transition will begin in the spring of 2004.

GSA will provide a part-time assistant, pay the costs of maintaining an editorial office, and reimburse journal-related travel expenses. Discretionary funds also are available.

Details on editor duties and desired qualifications are posted at www.geosociety.org. Go to "Publications Services," then to "Science Editors." If you are interested in this opportunity to help guide *GSA Bulletin*, one of the premier geoscience journals, submit a résumé and a letter describing relevant qualifications, experience, and objectives. If you are nominating someone, include a letter of nomination and the nominee's written permission and résumé. Send nominations and applications to Jon Olsen, Director of Publications, GSA, P.O. Box 9140, Boulder, CO 80301. **Deadline: December 31, 2003.**

Ads (or cancellations) must reach the GSA Advertising office one month prior. Contact Advertising Department, (303) 357-1053, 1-800-472-1988, ext. 1053, fax 303-357-1073, acrawford@geosociety.org. Please include address, phone number, and e-mail address with all correspondence.

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This position requires a Masters or Doctoral degree in geology, soil science, hydrogeology, geochemistry, environmental engineering, or related discipline. Additional requirements include established client base and marketing record.

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CALIFORNIA STATE UNIVERSITY
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The Department of Physics and Geology at California State University at Bakersfield (CSUB) announces a one year sabbatical replacement position in stratigraphy/sedimentology to be filled as at the lecturer level. A Ph.D. in the geological sciences is preferred but PhD candidates will also be considered. Experience with the stratigraphy of the San Joaquin Valley is also preferred but not required. The successful candidate would demonstrate a strong commitment to sharing in department responsibilities toward the education of K–12 teachers-in-training as well as majors courses. The successful candidate will also be expected to teach a graduate-level course in his/her area of expertise.

The geology program at CSUB has both undergraduate and masters degree programs. The department is equipped with aqueous chemistry and hydrology labs, an automated XRD, an ICP-MS, an SEM-EDX, a research petrography lab, a sedigraph and field geophysics equipment. The California Well Sample Repository houses the largest public collection of oil and water well cores and cuttings in California. The Geotechnology Training Center includes six SGI Octane workstations, 12 PCs, and surface and subsurface mapping software.

California State University at Bakersfield is a regional comprehensive university, which prides itself in a liberal arts approach to undergraduate education and small, high-quality graduate programs. It has an enrollment of approximately 8,000 students and resides in a rapidly growing community of over 400,000 people in the southern San Joaquin Valley of central California. The campus is conveniently located near popular beach, mountain, and desert attractions and is a two-hour drive from Los Angeles.

The starting date is September 1, 2003. Review of applications will begin July 15, 2003. Candidates should submit a letter of application, a current curriculum vitae, and names of at least three references to: Chair of the Geology Search Committee, Department of Physics and Geology, California State University, 9001 Stockdale Highway, Bakersfield, CA 93311-1099 USA.

Web site: http://www.cs.csubak.edu/Geology/.

CSU, Bakersfield is an AA/EOE. Applications from women, ethnic minorities, veterans, and individuals with disabilities are welcome.

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