a form of insurance known as weather derivatives has been developed in recent years. We discuss a Monte Carlo approach to the pricing of weather derivatives based on stochastic modeling of daily temperature. It will be shown that this approach can only be succesful if the time-series model correctly captures the autocorrelation structure of the data even at very high lags. Evidence will be presented that observed daily temperatures exhibit long-range dependence, i.e. power-law decay of the autocorrelation. This means that classical Box-Jenkins ARMA models are unequal to the task, since their autocorrelations decay exponentially. A generalisation of ARMA models which explicitly includes long-range dependence does however prove to be suitable, at least in some cases. We also briefly discuss the physical mechanisms which give rise to the long memory found in the data.

NG12B-1033 1330h POSTER

Evaluation and Quantification of Uncertainty in the Modeling of Contaminant Transport and Exposure Assessment at a Radioactive Waste Disposal Site

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The disposal of low-level radioactive waste (LLW) in the United States (U.S.) is a highly regulated undertaking. The U.S. Department of Energy (DOE), itself a large generator of such wastes, requires a substantial amount of analysis and assessment before permitting disposal of LLW at its facilities. One of the requirements that must be met in assessing the performance of a disposal site and technology is that a Performance Assessment (PA) demonstrate "reasonable expectation" that certain performance objectives, such as dose to a hypothetical future receptor, not be exceeded. The phrase "reasonable expectation" implies recognition of uncertainty in the assessment process.

In order for this uncertainty to be quantified and communicated to decision makers, the PA computer model must accept probabilistic (uncertain) input (parameter values) and produce results which reflect that uncertainty as it is propagated through the model calculations. The GoldSim modeling software was selected for the task due to its unique facility with both probabilistic analysis and radioactive contaminant transport. Probabilistic model parameters range from water content and other physical properties of alluvium to the activity of radionuclides disposed to the amount of time a future resident might be expected to spend tending a garden. Although these parameters govern processes which are defined in isolation as rather simple differential equations, the complex interaction of couple processes makes for a highly nonlinear system with often unanticipated results. The decision maker has the difficult job of evaluating the uncertainty of modeling results in the context of granting permission for LLW disposal. This job also involves the evaluation of alternatives, such as the selection of disposal technologies. Various scenarios can be evaluated in the model, so that the effects of, for example, using a thicker soil cap over the waste cell can be assessed. This ability to evaluate mitigation scenarios is of great utility in cost-benefit analysis.

In addition to providing decision makers with realistically uncertain modeling results, probabilistic assessment is also useful in understanding nonlinear model behavior and in guiding research efforts aimed at reducing the uncertainty in key components of the model. A sensitivity analysis of the modeling results identifies which model parameters are most significant (and over which ranges) in determining estimated doses, for example, thus providing justification for the allocation of limited research funding to reduce uncertainty in parameters that are both poorly constrained and significant to the model behavior.

NG12C MCC: Hall C Monday 1330h

Nonlinear Physical Properties of Geophysical Materials Posters *(joint with MR)*

Presiding: **K McCall,** University of Nevada, Reno**; R Guyer,** Los Alamos National Laboratory

NG12C-1034 1330h INVITED POSTER

Neutron Scattering and the Nonlinear Acoustic Properties of Rocks

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Although geomaterials (rocks) have been studied by macroscopic mechanical experiments for a very long time, the complexity, inhomogeneities, multiple phases, fluid content, interfaces, and lack of transparency have defied most experiments to resolve the corresponding microscopic behavior associated with a particular macroscopic observation. The microscopic origin of nonlinearity and hysteresis (end-point memory) evident in macroscopic stress-strain curves of rocks is still unknown after some 30 years of research by many groups, not to mention more recent low strain results like slow dynamics [see, *Physics Today*, **52**, 30-35 (1999)] or hysteretic temperature dependence [*Geophys. Res. Lett.*, **28**, 2293-2296 (2001)]. Although models of the P-M space variety have developed to a degree where some good qualitative agreement is reached, the link to the actual physical microscopic or atomic mechanism for hysteresis is still missing.

Neutron diffraction is one of a few experiments that can lead to an understanding of the atomic or microscopic effects that govern the properties of complex geomaterials. Neutrons can easily penetrate rocks [*Geophys. Res. Lett.*, **28**, 2105-2108, (2001)] and reveal properties of the bulk interior material (rather than the near-surface regions measurable, say, by X-rays). We are performing experiments with rocks on two beamlines at the Lujan neutron facility at Los Alamos where the scattering data will be correlated with some of the large body of nonlinear acoustic data which exists, to determine which atomic-plane level constituents of the rocks are active in nonlinear processes. We will describe the neutron scattering and acoustic experiments we are carrying out on marble and sandstone samples and will present our first results from the LANSCE neutron facility at Los Alamos. [Work supported by Office of Basic Energy Sciences, DOE, with Los Alamos National Laboratory Institutional Support.]

NG12C-1035 1330h POSTER

On Dynamic Nonlinear Elasticity and Small Strain

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We are addressing the question of whether or not there is a threshold strain behavior where anomalous nonlinear fast dynamics (ANFD) commences in rock and other similar solids, or if the elastic nonlinearity persists to the smallest measurable values. In qualitative measures of many rock types and other materials that behave in the same manner, we have not observed a threshold; however the only careful, small strain level study conducted under controlled conditions that we are aware of is that of TenCate et al. in Berea sandstone (*Phys. Rev. Lett.* **85**, 1020-1024 (2000)). This work indicates that in Berea sandstone, the elastic nonlinearity persists to the minimum measured strains of at least 10^{-8}. Recently, we have begun controlled experiments in other materials that exhibit ANFD in order to see whether or not they behave as Berea sandstone does. We are employing Youngs mode resonance to study resonance peak shift and amplitude variations as a function of drive level and detected strain level. In this type of experiment, the time average amplitude is recorded as the sample is driven by a continuous wave source from below to above the fundamental mode resonance. The drive level is increased, and the measurement is repeated progressively over larger and larger drive levels. Experiments are conducted at ambient pressure. Pure alumina ceramic is a material that is highly, elastically-nonlinear and nonporous, and therefore the significant influence of relative humidity on elastic nonlinear response that rock suffers is avoided. Temperature is carefully monitored. Measurements on pure alumina ceramic show that, like Berea sandstone, there is no threshold of elastic nonlinearity within our measurement capability. We are now studying other solids that exhibit ANFD including rock and mixed phase metal. These results indicate that elastic nonlinearity influences all elastic measurments on these solids including modulus and Q at ambient conditions. There appears to be no nonelastic linear behavior threshold in these solids.

NG12C-1036 1330h POSTER

A Dynamic Model of Hysteretic Elastic Sysytems

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The McCall-Guyer (MG) model for the description of elastic systems having hysteresis with end point memory, consists of a chain of hysteretic elastic elements with properties that depend on an Ising-like state variable. A system of coupled differential equations, one for the displacement field and a second for the state variable are introduced. These equations are the generalization to dynamics of the MG model. The state variable has Brownian dynamics in an energy landscape with structure that is sensitive to the forces which the elastic element must support. Numerical studies of the model yield behavior that compares well with the behavior of physical realizations of hysteretic elastic systems with end point memory, e.g., a Berea sandstone in both quasi-static and dynamic experiments. The generalization of the model to the cases where the elastic system is coupled to auxiliary fields and/or to a thermal reservoir is described.

NG12C-1037 1330h POSTER

Comparison of β Values in Rocks Deduced From the Elastoacoustic Effect and From 3-Wave Mixing

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We measure the changes in the speeds of sound in Berea, wet and dry, due to the application of non-isotropic stresses (elastoacoustic effect). From these measurements we deduce values of the 3rd order elastic constants, A, B, C. We insonify these same samples, immersed in a water tank, with well-characterized acoustic signals having frequency content $f_1 = 1.05MHz$ and $f_2 = 0.95MHz$. The nonlinear properties of the samples generate a difference frequency component at $\Delta f = 100kHz$ whose amplitude we measure (3-wave mixing). We analyze the combined effects of diffraction, attenuation, and nonlinearity on these difference frequency signals by means of the KZK equation, suitably modified to account for the actual frequency dependence of the attenuation in these samples. The attenuation of the higher frequency nonlinear signals, $f_1 + f_2, 2f_1, 2f_2$, precludes our ability to measure them. The values of β deduced from the 3-wave mixing measurements are in the hundreds whereas the values of β implied by the values of A, B, C are in the thousands. The same experiments on lucite yield β values consistent with each other: $\beta \approx 6$. In lucite we are easily able to measure the higher frequency nonlinear signals. The high attenuation in rocks precludes their measurement at these frequencies.

NG12C-1038 1330h POSTER

Ultrasonic Velocities in Lightly-Loaded Natural and Synthetic Granular Media*

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The seismic properties of near surface soils are of interest for a variety of problems, including pore fluid identification and tracking, wave propagation modeling, geotechnical site characterization, static corrections for reflection seismology, and locating underground objects. Ultrasonic velocities increase rapidly when a granular material is loaded as contact stress and area and coordination number of grain contacts increase. Porosity, grain size and distribution, grain shape, and mineralogy all play a role in determining this nonlinear response. We adapted the ultrasonic pulse transmission method to measure compressional (P) and shear (S) wave velocities at ultrasonic frequencies (100-500 kHz) for lightly loaded artificial soils (to 0.1 MPa maximum). Samples were fabricated from Ottawa sand (some with montmorillonite added), Santa Cruz beach aggregate, artificial glass beads, and alumina spheres. All materials were characterized with the SEM before the experiments. We focused on packing, mineralogy, and hysteretic effects in our study and found that compressional velocities vary from 200 to 700 m/s over the narrow loading range investigated as a result of these effects. In light cyclic loading of pure Ottawa sand we observed hysteretic effects in the shear mode velocity, implicating sticking of the grains. Our measurements demonstrate a cubic relationship between stress and compressional wave velocity for pure quartz sand, as predicted by Hertzian contact theory when grain roughness is incorporated. The sand/clay mixtures were found to have very different properties from pure sand. The clay bridged sand grains creating more area at the contacts and higher sound speeds over the narrow loading range, but suppressed the strong nonlinear behavior predicted by Hertzian contact theory.

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NG12C-1039 1330h POSTER

Instabilities of stressed crystal surfaces in contact with a fluid

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The rheology of the Earth's crust is closely related to the deformation under stress of the mineral grains. In sedimentary rocks and many metamorphic systems matter transport in the fluid phase makes dissolution-precipitation processes the most effective pathway for mineral deformation.

Earlier studies on the dissolution of stressed crystals in undersaturated solutions have shown that stress corrosion can lead to roughening of interfaces. The corrosion pattern develops due to gradients in elastic energy along a free crystal surface with an initial random noise-like roughness. This so called Assaro-Tiller-Grinfeld instability has a positive feedback because dissolution will cause further increase in elastic energy, which in turn will speed up dissolution.

We have performed experiments on soluble brittle salts in saturated solutions as an analogue of minerals in the Earth's crust. We have studied the onset of the Assaro-Tiller-Grinfeld instability and the nonlinear evolution of corrosion-precipitation patterns beyond the initial surface roughening. In the experiments we stress small crystals of NaClO3 in a saturated solution and monitor the evolving surface patterns in situ with a video camera.

Our experiments show that stress corrosion-recipitation can lead to a non-stable roughness (Assaro-Tiller-Grinfeld instability) that develops deep grooves on the crystal surface. The system then breaks its symmetry and undergoes a secondary instability, an imperfect period doubling that produces a coarsening of the surface roughness. During the coarsening grooves travel upwards on the crystal surface which suggests that there are concentration gradients in the fluid next to the crystal. While the pattern coarsens and the wavelength between neighbouring grooves grows the pattern changes from a one dimensional structure of parallel horizontal grooves to a two dimensional structure with horizontal and vertical grooves. Finally, one large groove travels across the crystal surface leaving behind a perfectly flat crystal.

Our experiments suggest that stress corrosion-precipitation is a transient mechanism that can lead to a new equilibrium of the solid-fluid system under stress.

NG12C-1040 1330h POSTER

Universal scaling in transient creep

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When aggregates of small grains are pressed together in the presence of small amounts of solvent the aggregate compacts and the grains tend to stick together. This happens to salt and sugar in humid air, and to sediments when buried in the Earths crust. Stress concentration at the grain contacts cause local dissolution, diffusion of the dissolved material out of the interface and deposition on the less stressed faces of the grains. This process, in geology known as pressure solution creep, plays a central role during compaction of sedimentary basins during tectonic deformation of the Earth's crust in strengthening of active fault gouges following earthquakes and in ceramics. Experimental data on pressure solution creep has so far not been sufficiently accurate to understand the transient processes at the grain scale. Here we present experimental evidence that pressure solution creep does not establish a steady state interface microstructure as previously thought. Conversely, pressure solution creep strain and the characteristic size of interface microstructures grow as the cubic root of time. Transient creep with the same scaling is known in metallurgy (Andrade creep). The apparent universal scaling of pressure solution transient creep is explained here using an analogy with spinodal dewetting.

NG12C-1041 1330h POSTER

Scaling invariance of stylolites roughness

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Stylolites are thin irregular rock-rock interface zones that are formes via the stress induced dissolution and precipitation of sedimentary (usually monomineralic) rocks such as sandstones, limestones or evaporites. Twenty two limestone stylolites surfaces have been opened and sampled using several profiling techniques at laboratory scale: mechanical profiler, laser profiler and stereophotography. Three families of stylolites are described in terms of self-affinity. We used two independent analysis techniques of the topography measurement: Fourier and Wavelet spectra. Both are consistent and show two regimes of self-affinity. At low scales, the roughness exponent is ζ_1=1.1 and significanltly different from that of large scales: ζ_2=0.5. The cross-over length is show to be different for each family of stylolites and controls the eyes aspect of the stylolites. No significant anisotropy of the roughness is observed. When considering the cross-over length, a collapse of the different roughness spectra can be obtained and leads to a unified description of stylolites roughness.

NG12C-1042 1330h POSTER

Re-Thinking the Contradictions of Soil Moisture Spatial Variability

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In 1998, Famiglietti and his coauthors noted two contractions in the literature related to spatial variability of soil moisture fields. The first relates to the increase or decrease in soil moisture variance with the mean soil moisture, and the second relates to the ability of topographic indices or other measures of topography to explain the spatial pattern of soil moisture. Through analyzing remotely-sensed soil moisture data collected during three field campaigns (i.e., Moonson'90, Washita'92, and SGP'97), it was found that: (1) the relationship of mean soil moisture and variance depends on mean soil moisture state, i.e., soil moisture variance increases during dry-down process if mean soil moisture is between porosity and field capacity, otherwise variance decreases with dry-down if mean soil moisture is less than field capacity; (2) Without considering the correlation between rainfall and topography, topographic effects on soil moisture could be misinterpreted; and (3) soil moisture fields show three distinct scaling regimes during dry-down periods, i.e., atmospheric-dominated; transitional; and land surface characteristic-dominated.

NG21A MCC: Hall C Tuesday 0830h

Nonlinearity and Nonlocality in Hydrology and Geophysical Transport Processes Posters *(joint with H)*

Presiding: **D Benson,** Desert Research Institute**; M Meerschaert,** University of Nevada

NG21A-0924 0830h POSTER

Controlled-source Electromagnetic Responses of Spatially Hierarchial Geological Media

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The controlled-source electromagnetic (CSEM) induction technique is gaining importance as a valuable near-surface geophysical tool for hydrogeophysical site assessment. However, CSEM responses are oftentimes difficult to interpret owing to the complexity of the host geological environmemnt. Bedding planes, joints, fracture zones, and other geological features conspire to generate a medium in which electrical conductivity is variable over a hierarchy of spatial scales. Rocks at each length scale offer different patterns of heterogeneity that reflect the complex interplay of their formative geological processes. The result is a rough, spatially hierarchial geological structure that leaves a similar imprint on the electrical conductivity structure. Even though CSEM induction obeys diffusive physics and is therefore inherently a smoothing operation, observed CSEM responses from a variety of geological settings have in common very rough spatial variability. In fact, CSEM profiles invariably are examples of fractional Brownian motion (fBm) signals. Existing algorithms for forward modeling of CSEM responses solve however the governing Maxwell equations in piecewise constant gridblocks of electrical conductivity. This pragmatic view of the subsurface electrical structure is outdated and inaccurate. The purpose of my presentation is to introduce hydrogeophysicists to the fractal nature of observed CSEM responses and to develop new concepts in forward modeling taking into account rough, spatially hierachial electrical conductivity structures. The CSEM response of man-made, non-fractal objects embedded in a fractal geological medium is also discussed in the context of target detection and discrimination algorithms. Practical applications to problems in applied hydrogeophysical investigations are emphasized.