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October 25, 2000

Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
Office of Nuclear Material Safety and Safeguards
Mail Stop 8 A23
Washington, DC 20555

Subject: Submittal of Abstracts: (1) The Geometric Strength of Fault Systems, (2) Development of Synthetic Layer Dip Adjacent to Normal Faults and Implications for Traps, Barriers and Migration Pathways, and (3) Progressive Development of Structural Geometries and Concomitant Loss of Connectivity: Examples from Analog Models.

Dear Mrs. DeMarco:

The purpose of this letter is to transmit the three subject abstracts for review and information to the NRC. The papers will be presented at the annual meeting of the American Association of Petroleum Geologists (AAPG). This meeting is to be held in Denver in June of 2001. The AAPG does not require a full paper.

The first abstract, The Geometric Strength of Fault Systems, was previously approved. This abstract was submitted earlier in a letter Sagar to DeMarco, dated September 25, 1999. It was originally intended for a conference in September in London. Higher priority activities caused cancellation of our attendance at the meeting. This is being resubmitted because of the change of meeting.

The second and third abstracts are based on work supported by the Japanese National Oil Company. The concepts presented in these two abstracts, while not developed with NRC funding, will be used where appropriate on NRC tasks. NRC will not incur costs of presenting these abstracts at the AAPG meeting.

Should you have any questions regarding this, please contact Mr. Darrell Sims at (210) 522-6829, Dr. David Ferrill at (210) 522-6082, or Dr. H. Lawrence McKague at (210) 522-5183.

Sincerely,

Budhi Sagar
Technical Director

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Attachments
cc: J. Linehan, W. Reamer, E. Whitt, B. Meehan, J. Greeves, P. Justus, W. Patrick, CNWRA Dirs, CNWRA EMs, D. Ferrill, D. Sims, J. Stamatakos, D. Waiting, A. Morris, M. Ferguson

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The Geometric Strength of Fault Systems

FERRILL, DAVID A., DARRELL SIMS, JOHN A. STAMATAKOS, all at *CNWRA*, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238; ALAN P. MORRIS, Division of Earth and Physical Sciences, University of Texas at San Antonio, San Antonio, TX 78249

Faults optimally oriented for slip within the ambient stress field are geometrically weak compared with other fault orientations in the system. As a fault system evolves it undergoes changes that lead to both geometric strengthening and weakening of faults within the system. Given a single stress regime, geometrically weak faults grow and accumulate displacement, and geometrically strong faults tend to be abandoned. This natural selection process results in a well-organized fault pattern that reflects the ambient stress field.

Our work in normal fault systems indicates that initial fault surfaces are often en echelon and physically detached from one another. These faults grow by segment nucleation, growth, and connection by curved propagation or connecting fault formation. Fault propagation prior to linkage produces locally perturbed stress fields that modify continuing fault propagation. As fault segments link, local perturbations in the stress field are relieved and relict fault patches, developed in locally perturbed stress fields, become geometrically stronger in the ambient stress field. Once linked, the poorly oriented fault patches are bypassed by cutoff faults that straighten the overall fault surface. These geometrically strong fault patches are cut off by more ideally oriented fault segments, resulting in a smoother, smaller, and geometrically weaker active fault surface. In addition, slip on an array of parallel normal faults progressively reorients fault planes. For example, horizontal-axis rotation (tilting) can rotate faults that were initially weak to shallower and less favorable dips, making them geometrically stronger, and causing the initiation of new, more favorably oriented faults.

These same general processes of progressive deformation apply equally well to faults in strike-slip and contractional settings. For example, progressive steepening of closely spaced thrust slices in imbricate fans and duplexes (e.g., antiformal stacks) rotates faults to steeper and less favorable orientations for slip thereby geometrically strengthening the faults. In strike-slip settings displacement on two overlapping right-stepping right-lateral strike-slip faults initially produces localized extension and the development of a pull-apart basin bounded by normal faults. These faults initially respond to the local stress field in the overlap region and connect to and transfer displacement between the strike-slip faults. Continued strike-slip displacement leads to a more optimally oriented cross-basin strike-slip fault system. This process of fault straightening produces a smoother, smaller, and geometrically weaker active fault surface.

Work supported by the U.S. NRC (Contract NRC-02-97-009). This work is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

Development of synthetic layer dip adjacent to normal faults and implications for traps, barriers, and migration pathways

FERRILL, DAVID A., DARRELL SIMS, DEBORAH WAITING, all at *CNWRA*, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238; ALAN P. MORRIS, Division of Earth and Physical Sciences, University of Texas at San Antonio, San Antonio, TX 78249; and SHUTARO HASEGAWA, Japan National Oil Corporation, Technology Research Center, Mihama-ku, Chiba-shi 261-0025, Japan

Field analyses of normal faulting in the Paradox Basin of southeastern Utah (vicinity of Moab, Utah) and northern Rio Grande Rift of New Mexico (vicinity of Albuquerque, New Mexico), considered with examples from new analog modeling and seismic reflection data, have led us to recognize the importance of synthetic layer dip associated with normal faults. These synthetic dip panels are developed where layers on upthrown, downthrown, or both sides of a normal fault dip in the same direction as the fault. Synthetic dip panels adjacent to normal faults should be expected at some scale in all normal fault systems. In addition to faults developed in strata with a regional dip, six fault-related mechanisms for the development of synthetic dip are: antilistric fault bend, faulted monocline, distributed shear, shear in overlap between vertically or laterally segmented faults, fault block impingement and contraction, and differential subsidence by footwall or hanging wall collapse. Development of synthetic dip accommodates a component of throw by tilting or folding, thereby reducing the offset or true displacement on the related normal faults. Fault block deformation is strongly dependent on the mechanisms that produce synthetic dip panels, and may influence fault zone and fault block permeability. Depending on stratigraphic and structural relationships, synthetic dip panels can produce downthrown closure for hydrocarbon trapping, provide fluid migration and/or production communication pathways across faults, or produce barriers to fluid communication across faults.

Progressive development of structural geometries and concomitant loss of reservoir connectivity; examples from analog models.

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We conducted analog modeling (sandbox) experiments as a new approach to determining reservoir connectivity coupled to developing structural geometry. Progressive deformation of the models results in features indicating that the potential for hydrocarbon trapping and compartmentalization increases as fault systems mature. Conversely, the potential for reservoir communication over large areas decreases as structures develop. For example, experiments of distributed extension (deformation over a rubber sheet) demonstrate that geometrically simple faults nucleate at a large number of sites distributed across the deforming region, with incipient relay ramp structures between fault tips and forced folds over blind faults serving as potential hydrocarbon pathways. Further deformation results in increased geometric complexity as faults grow and interact. Potential reservoir communication pathways are severed as faults merge by lateral and upward propagation or ramp breaching, producing progressively more opportunities for trapping and compartmentalization, and resulting in decreased connectivity and greater structural relief. The experiments demonstrate that this geometric evolution occurs at many scales. Basin bounding faults show clear, large-scale examples of the geometric maturation of potential hydrocarbon communication pathways (e.g., relay structures) into potential hydrocarbon traps (e.g., breached relay ramps or faults merged by lateral propagation). In the models, these same processes also occur within the deformed region at smaller scales. Analog models of contractional and strike-slip deformation exhibit similar relationships between degree of structural development and reservoir connectivity. Progressive deformation leads to a large population of structures in a single structural setting, each with potential for hydrocarbon communication or isolation, depending upon structural maturity of the whole system. In addition to the controls of structural regime and stratigraphy, our models demonstrate that the degree of compartmentalization strongly depends upon stage or maturity of structural development.