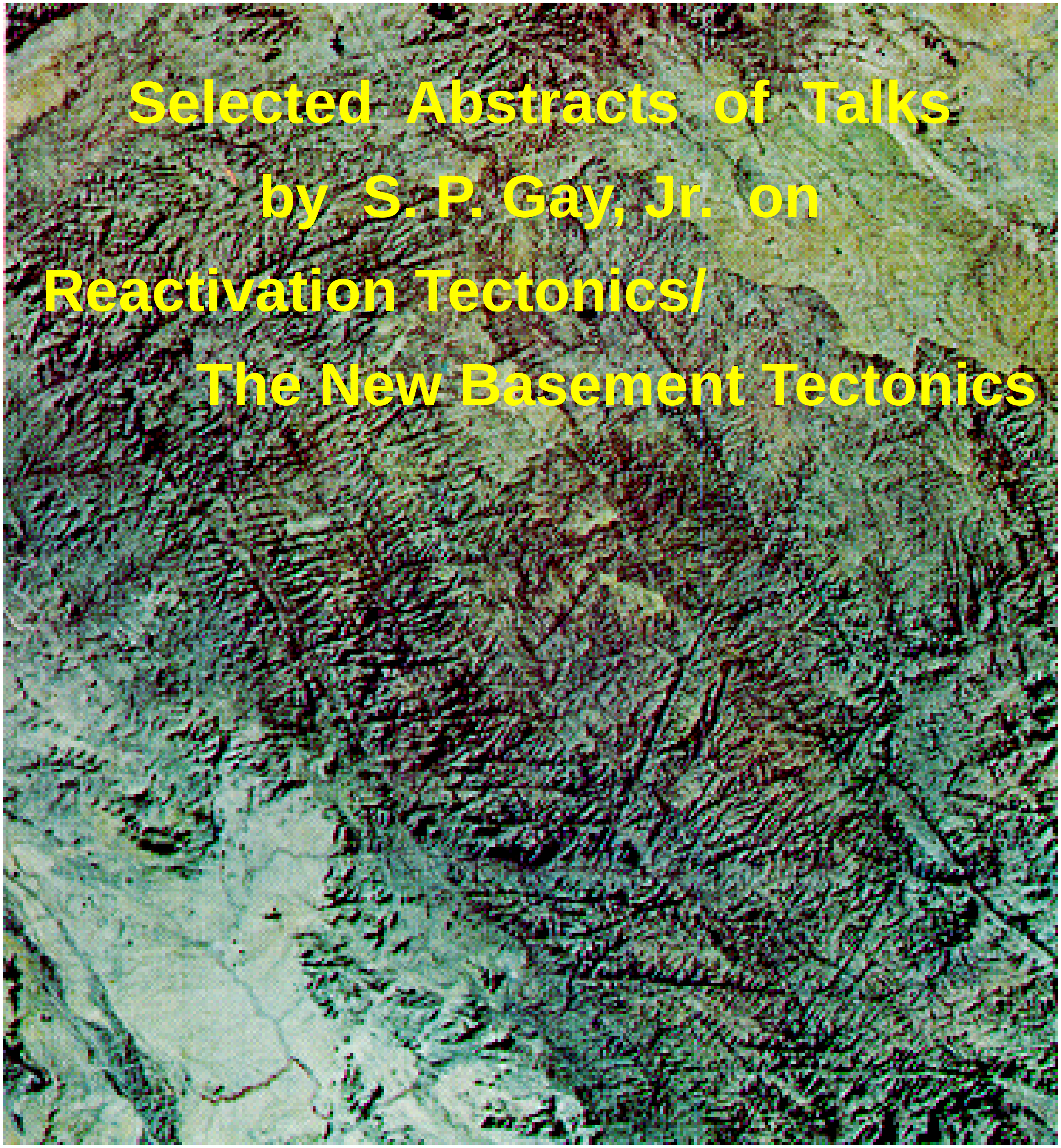
Selected Abstracts of Talks by S. P. Gay, Jr. on Reactivation Tectonics/ The New Basement Tectonics



BASEMENT REACTIVATION

LIST of SELECTED ABSTRACTS of TALKS by S.P. GAY

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Keynote Address
Presented at 10th Int'l Conf. on Basement Tectonics
August 4th, 1992 - Duluth, MN

Basement Control Within the Sedimentary Section, as Determined from Subsurface Mapping and Residual Aeromagnetic Data[1]

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ABSTRACT

Basement geologic control on the overlying sedimentary section manifests itself in two basic ways: 1) folding of the sedimentary section due to compaction of the sedimentary rocks over the underlying basement topography, and 2) fault movement within the sedimentary section from faults propagated up from the underlying brittle basement. The first category, basement topographic control, has been a subject of dispute for decades. First proposed independently by three prominent U.S. g1eologists in 1920, structural control by gravitational compaction was gradually but resou1n1dingly rejected with time in favor of folding due to horizontal compressive stress, a la strain theory. This rejection proceeded to the extent that many of the popular structural textbooks of the last two decades do not even consider gravitational compaction over basement topography as a structure-forming mechanism. However, a detailed study published in 1985 and again in 1989, showed that, of thirty basement hills documented by drilled-out-cross-sections in the U.S. Midcontinent, thirty of them (100%) give rise to compactional anticlines. Compaction as a cause of structure in the sedimentary section has thus leapt from obscurity to prominence in the course of a few years.

The second category of basement control, rejuvenation or reactivation of old basement faults as a cause of structure in overlying rocks, is a subject that has been dear to the hearts of many geologists over the years, especially field geologists, and although zealous advocates of strain theory would have liked this subject to have died out as well (it was always a thorn in their side), reactivation of basement faults as a cause of structure is alive and well. The Basement Tectonics Conferences are, in a sense, a rebellion of many structural geologists against the well established structural dogma epitomized by strain theory. The writer will show a handful of examples, selected from among hundreds, of structural and stratigraphic features within the sedimentary section that lie over old basement shear zones mapped by residual magnetic methods, thus proving the pervasive nature of basement fault control.

If basement control of structure is so pervasive, and so basic, what does that signify for strain theory concepts as explained in present-day structure textbooks and taught by university geology courses? At the very least, this material is vastly out of date and needs profound modification to be of value to geology students and the geology profession in general.

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[1]Keynote Talk, 10th International Conference on Basement Tectonics, August 4th Technical Session, Duluth, Minnesota, 1992.

Presented at: 1. AAPG Annual Meeting, Denver, Colorado, June 15, 1994
2. AAPG Rocky Mtn. Section Mtg., Reno, Nevada, July 19, 1995 (Invited)
3. CSEG /HRAM Forum, Calgary, Alberta, November 18, 1997 (Invited)

BASEMENT CONTROL OF OIL AND GAS TRAPS: MORE COMMON THAN WE THOUGHT? AN UPDATE

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ABSTRACT

Mapping of the basement fault block pattern in 21 petroleum basins throughout the United States has revealed literally hundreds of correlations of aeromagnetically defined basement faults, or shear zones, with oil and gas traps and structures. These range from simple fault traps, to thrust-folds, to horst blocks, to dolomitized fracture systems, to asymmetric folds over reverse faults. Additionally, many types of stratigraphic traps correlate with basement shear zones. Some examples are Cretaceous algal mounds in the Paradox Basin that evidently formed on fault scarps on the sea floor, oolite shoals in Kansas, also on subsea fault scarps, offshore sand bars in the Powder River Basin that formed over fault-caused sea floor highs, and shoreface bars in the Washakie Basin that yield up to 1 tcf of gas. A separate category of basement related oil and gas traps are gravitationally-induced compaction structures, or graviclines.

A popular wall chart by N.J. Hyne lists 29 basic types of oil and gas traps. Of these 29, our studies demonstrate that 20 of them (70%) can, and do, result from basement control. We will show actual field examples of most of these categories, substantiated by aeromagnetic basement mapping and subsurface well control.

Basement control is thus very real and very pervasive in structural and stratigraphic geology, and although it is not a subject we learn in college or even in professional short courses, it is an important factor in the formation of a high percentage of oil and gas traps and reservoirs.

Presented to Soc. of Prof. Well Log Analysts
Canton, Ohio - March 28, 1996 (Invited)

The Basement Fault Block Pattern: Its Importance in Petroleum Exploration, and Its Delineation with Residual Aeromagnetic Techniques[1]

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ABSTRACT

Multiple episodes of tectonism, related to plate tectonic movement during ≈ 4 billion years of Precambrian time, created complex patterns of basement shearing and faulting in the earth's crystalline crust. The fracture patterns thus created are observable on space imagery of outcropping shield areas on all the continents, and would necessarily exist as well under all sedimentary basins deposited on the basement complex of the cratons. Such cratonic basins comprise the majority of the oil and gas producing sedimentary basins of the world, including the Appalachian Basin. Subsequent movements of the basement faults and of the rigid to semi-rigid blocks between them occurred periodically during, and subsequent to, deposition of the sedimentary rocks and localized most of the structure and much of the stratigraphy in the sedimentary section. This basement fault block pattern also controls, to large degree, the topography of the basement through erosion. The topography, in turn, controls additional structure and stratigraphy through the mechanism of gravitational compaction.

In this talk I will show a number of one-on-one correlations of the basement fault block pattern, as mapped by modern aeromagnetic techniques, with structural and stratigraphic features in the sedimentary section that are important to petroleum exploration. Several pitfalls in aeromagnetic interpretation that have been detrimental to the use of aeromagnetics in petroleum exploration in the past are shown to be due to the failure to recognize the existence of the basement fault block pattern and its control on the lithology of basement. It is these basement lithologic changes, and the resulting magnetic susceptibility changes from block to block, that generally prevent us from determining the direction of throw of faults, but do allow us to map the basement fault block pattern and to use this pattern in important new ways for finding oil and gas accumulations.

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[1]An AGI POSITION PAPER on the Recommended Use of Airborne Magnetics in Petroleum Exploration. Published 1995, in the Proceedings Volume of the 10th Basement Tectonics Conference, R.W. Ojakangas, Editor.

Presented at:

1. AAPG Rocky Mountain Section meeting, Denver, August 25, 1997
2. Denver Geophysical Society meeting, January 8, 1998
3. Wyoming Geological Association meeting, Casper, April 4, 1998 (Invited)

The Powder River Basin - A Classic Area of Basement Control on Oil & Gas Fields, Including a Number of "Purely Stratigraphic Traps"

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Abstract

In the Powder River Basin most of the prolific oil producing formations were laid down during the Cretaceous period contemporaneously with the Laramide orogeny. This powerful EW or ENE-directed compressional event strongly affected depositional patterns in the strata and created many of the traps and/or reservoirs into which oil migrated.

Given the fault block nature of basement and the occurrences of weakness zones bounding these blocks - the subject of previous presentations by the author - it is not difficult to imagine that there should be basement control of individual oil fields. The basement fault block pattern has not been mappable under thick sedimentary cover in the past with any of the common geological or geophysical techniques, but it is possible to map these blocks using properly acquired, processed, and interpreted aeromagnetic data. Comparisons of this type of mapping with well known traps and reservoirs in the basin have shown many one-on-one correlations, indicating that the following types of basement control have taken place:

1. Frontier-Dakota formations - asymmetric folds created during Laramide compression by high angle reverse faults over basement weakness zones,

2. Muddy formation - channels following low topography in the underlying shale resulting from erosion of more highly jointed areas located over basement faults,

3. Shannon, Sussex, Ferguson, Tecla, Teapot sands - sand bars that apparently formed from the winnowing action of bottom currents flowing over sea floor highs resulting from high angle reverse faults at basement level.

I will show examples of about 20 individual oil fields that fall in the above categories, including Poison Draw, Hartzog Draw, Dead Horse-Barber Creek, Salt Creek, Big Muddy, Kitty, Fiddler Creek, and Clareton. I will also show a field in the Washakie Basin underlain by a causative basement fault well-mapped by magnetics that is not imaged by 3D seismic.

Presented at Annual Geological Society of America Meeting,
Denver, Colorado, 28 October 1999

15-Year Study in 21 U.S. Sedimentary Basins Shows the Majority of Faults Are Reactivated Basement Shear Zones

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Extensive basement fault mapping in U.S. sedimentary basins over the last 15 years has shown that most faults (65%-100%) in the sedimentary section are located over underlying basement faults (shear zones). Additionally, many stratigraphic features, such as offshore sand bars, shoreline bars, fluvial sands, oolite shoals, and bioherms of various types are located over, or adjacent to, the mapped basement faults. To make these comparisons, we used only faults in the sedimentary section and sedimentary features that are reliably known to exist and accurately located by detailed subsurface (well) data, and in some cases, seismic data. Case history volumes of oil and gas fields by local geological societies as well as proprietary and commercially available petroleum industry maps have been our main source of detailed, accurate geology. To these we have compared detailed basement fault maps prepared from high-resolution aeromagnetic surveys flown at a line spacing of one-third to one-half depth to basement with sampling rates of 0.1 to 1.0 seconds and processed using state-of-the-art compilation techniques. Second derivative or residual aeromagnetic maps were computed to enhance the basement anomalies, and the fault trends were then placed along gradient lines between magnetic highs and lows or truncation lines (terminations) of anomalies. Basement shear zones are located along the magnetic gradients because of rock type changes, and hence magnetic susceptibility changes, that occur across them.

We have made fault comparisons in 21 U.S. sedimentary basins over a combined area of about 750,000 km^2, slightly larger than the size of Texas, and have found hundreds of correlating faults and dozens of correlating sedimentary features. We believe this proves beyond a doubt that most faulting in the sedimentary section results from reactivation of basement shear zones and that little, if any, is due to fracturing at ±30° to maximum compressive stress, as hypothesized by strain theory ("Andersonian theory of stress"). This finding has implications that go far beyond the areas studied.

Presented to the Dept. Of Geology, University of WV, Morgantown
October 25, 2000 (Invited)

Basement Control of Structure and Stratigraphy in the Rockies: Are there Analogs in Appalachia?

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ABSTRACT

Basement fault mapping in the Rocky Mountain petroleum basins with magnetics in the last 17 years has demonstrated that reactivation of basement faults has controlled the locations of a majority of the structural traps and possible a majority of the stratigraphic traps present in that region. The most obvious result of basement control, very common in many basins, are Laramide-age "thrust-fold structures," i.e. asymmetric compressional anticlines, located in the hanging walls of basement-rooted thrusts. We have spectacular and extensive examples of these from the Big Horn, Green River, Powder River and Wind River Basins. The largest of these structures, Salt Creek field, has already produced 680 Mbo. Stratigraphic traps of the fluvial type, i.e. old river channels, will be shown of upper Cretaceous Muddy fm sands in the Powder River Basin. Also in the Powder River Basin, we have many examples of offshore sandbars that apparently formed by the winnowing action of bottom currents over old sea floor highs. The sea floor highs are due to Laramide (Late Cretaceous-Early Tertiary) compression that reactivated basement faults. One of these fields, Hartzog Draw, has ultimate recoverable reserves exceeding 200 Mbo. In the Paradox Basin stratigraphic traps in carbonate rocks include Pennsylvania algal mounds that formed on fault scarps on the sea floor, again over old basement faults.

One of the more interesting findings of our studies in the Rockies is the control of shoreface sands localized along basement faults that evidently formed topographic breaks in Late Cretaceous time. A detailed 3D seismic survey over one of these fields, Standard Draw in the Green River Basin, a 1 tcf gas field, failed to map a basement fault that was clearly visible on the aeromagnetic survey. This was because the throw, possibly only a few tens of feet, was below the level of resolution of the seismic survey, whereas it was seen by magnetics because it occurred at the interface between two different basement rock types.

In the Appalachians, more comparisons by exploration personnel of known stratigraphic and structural traps with basement faults are necessary before it can be ascertained if the degree of basement control is as great as it is in the Rockies. My assessment is that it will be the same, but a lot of work will be required to make this determination. A few examples of basement control from the Appalachian Basin will be shown, but more examples are not possible due to the sparcity of published case histories of oil fields.

Presented at the Wyoming Geological Assoc., Luncheon Meeting
Casper, Wyoming, March 9, 2001 (Invited)

ANTICLINES IN WYOMING: A DEMONSTRATION OF THE REACTIVATION OF PRE-EXISTING BASEMENT FAULTS

ABSTRACT

Anticlines have been some of Wyoming's most prolific oil producing structures, the Salt Creek Field in the Powder River Basin being one of the U.S.'s truly giant fields with reserves of over 650 million barrels, not to mention Lost Soldier in the Wind River Basin with reserves of 360 million barrels.

The former was discovered in 1908, the latter in 1916, both from their surface expressions during the period when "anticlinal theory" reigned supreme in the oil patch. After over a hundred years of looking for, drilling on, and studying anticlines, one would think that we have nothing further to learn about these interesting structures. However, that may not be the case. A few years ago the writer became interested in what is responsible for the "end closure" on anticlines that give these structures 4-way closure. It is accepted that anticlines result from shortening of the sedimentary section as visible in cross-sections across the long axis. The basement shortens an equivalent amount underneath by reverse faulting. But if there is shortening or compression in the transverse direction, there must also be shortening in the longitudinal direction as proven by the existence of "end closure." It will be demonstrated that longitudinal compression results from reactivation of pre-existing basement faults not at right angles to maximum compressive stress. In fact, as this angle changes from perpendicular to a more oblique direction, anticlines become shorter and more dome-shaped. Becoming more oblique still, the reactivated basement fault would exhibit only strike-slip movement. There is thus a continuum from long, narrow anticlines to short, domal anticlines to no anticlines as the strike of the underlying fault changes relative to the regional stress field. These deductions will be supported by showing aeromagnetically mapped basement faults that give rise to anticlines in the Powder River, Big Horn, Wind River, and Green River Basins.

Presented at PTTC Trenton 2 Workshop
Morgantown, West Virginia, May 1, 2001
Invited Speaker

Basement Fault Control on Black River-Trenton Oil and Gas Production in Michigan, New York, and West Virginia

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ABSTRACT

The prolific Albion-Scipio field was discovered in southern Michigan in 1956, and 5 years later the field had 420 producing wells that defined a linear structure nearly 35 miles long and less than one mile wide. The reservoir rock is fractured secondary dolomite that has replaced the normal Black River-Trenton limestone facies within the field boundaries. A definitive report of the field written by geologist Garland D. Ells for the Michigan Geological Survey the next year suggested that the fracturing which provided the pathways for the dolomitizing fluids arose from movement along an underlying basement fault coincident with the field. In the mining industry the same sequence of geologic events gives rise to the so-called "Mississippi Valley-type" lead-zinc deposits. Ells stated "there is no direct evidence to substantiate the assumption [of a basement fault]" under Albion-Scipio, and a number of oil companies apparently used magnetic methods without sucess to try to map the fault. The author knows of one such attempt by Unocal that occurred in the early 1980's and was not successful. However, in 1986, Applied Geophysics, Inc. completed a 5000 square mile aeromagnetic survey of southern Michigan and applied their newly developed NewMag® profile residual techniques to the data, which clearly showed a pair of closely spaced parallel basement faults coincident with the field. Similar basement faults were mapped under the Stony Point, Hanover, Deerfield and Northville Black River-Trenton fields and at nine other places of minor production from the Black River-Trenton formation in southern Michigan.

In New York state the prolific Gray well in Steuben County is coincident with a NewMag® mapped basement fault, as are the Parker and Epling wells in Roane County, West Virginia. I will show the magnetic data from which we derived the above mentioned basement fault locations, and also magnetically mapped basement faults coincident with the Savage lead-zinc mine in central Tennessee and the New Lead Belt in southeast Missouri.

Presented at the IAGOD International Workshop,
Deep Structure of the Earth and Concentration of Metals in the Lithosphere: A Geodynamic Approach,
NASA Goddard Space Flight Center, Greenbelt, MD, USA
Sept. 17, 2001

The use of regional, but detailed, aeromagnetic data to define the fault pattern in Precambrian basement, the plumbing system for mineral concentrations in the lithosphere

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ABSTRACT

Hydrothermalists accept as fact the idea that faults in the basement metamorphic complex serve as conduits ("plumbing") for rising magmas and fluids coming from the lower crust and mantle and that these magmas and fluids give rise to ore concentrations by precipitation near the earth's surface. However, the spatial characteristics of the transmissive basement faults are little known, nor is there consensus as to their age. Were they formed contemporaneously by the lower density magmatic fluids as they rose, or are they part of a pre-existing pervasive network of basement faults of considerable antiquity? The author hypothesizes that the latter is true and in support of this, will show that basement shear zones/faults have controlled almost all faults that cut the Phanerozoic sedimentary section in cratonic petroleum basins. This is proven by comparing pre-existing basement fault locations mapped by state-of-the-art aeromagnetic processing and interpretation techniques with the detailed and voluminous subsurface mapping and seismic data generated by the petroleum industry. If this observation holds true for rocks in petroleum basins for the last 500 million years or so, it certainly holds true for hard-rock areas, i.e. the remainder of continental crust during the same time period. By scientific extension, it probably holds true for all continental crust during much, or all, of earth's history. To summarize: earth's crust is cut by a pervasive fracture pattern that formed in Archean or Early Proterozoic time, has been reactivated numerous times since, controls much, or most, later geology, including emplacement of mineral-rich plutons, and is mappable, to large degree, with modern aeromagnetic methods. As an example, the attached magnetic map of the Boulder Batholith in southwest Montana, USA, shows a prominent north-south disruption in the data corresponding to the 65 km long Continental fault. This fault evidently localized the mineralizing solutions responsible for the Butte Mining District, one of the largest mining districts in the United States.

Presented at 16th Basement Tectonics Conference
Rolla, Missouri, May, 20, 2002

JOINTING, LINEARS, AND LINEAMENTS - THE BASEMENT CONNECTION

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Abstract

Although some geologists understand the basic connection between basement faults, jointing, linears, and lineaments, the majority do not, and a few even disparage the idea of a connection. Few geology teachers pass on the understanding of the basement connection to their students, although almost all geologists will be concerned at some time in their careers with jointing, linears, and/or lineaments and should understand these very common geological features. It is for this reason that I will here review past and present knowledge of jointing, linears and lineaments and outline the proofs of their interconnected origin via basement faults. This should dispense with the mystery long surrounding these (as some say) enigmatic geologic features.

Briefly, small meter-scale movements of basement faults under recently lithified sedimentary rock create joints. These joints are parallel and cover large areas because the underlying basement faults (actually shear zones) are parallel and cover large areas. Most areas are underlain by three or more basement fault sets, thus resulting in multiple directions of jointing. Some joints may result from later stresses in the sedimentary section that create folding and faulting. Basement-created joints are not evenly spaced, and where they are more numerous due to inhomogeneities in the sedimentary section and/or where groundwater is channeled along them, airphoto and Landsat lineaments result - features which are parallel to, but not necessarily coincident with, the underlying causative basement faults. Additional movement of some of the basement faults will, of course, result in fracturing and the formation of faults, linears, and lineaments that are directly coincident with the underlying faults.

Presented at the Conference on Naturally Fractured Reservoirs
Oklahoma City, June 3-4, 2002
Published on CD

THE ORIGIN OF NATURAL FRACTURING

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ABSTRACT

Natural fracturing is extremely important in many oil and gas reservoirs in allowing fluids to flow efficiently into a well-bore. In many cases natural fracturing means the difference between a commercial well and a dry hole. Techniques abound for taking advantage of, and enhancing, the fractures around a well-bore to increase fluid flow into the well, and millions upon millions of dollars have been, and are being, spent both by private industry and government to understand, augment, and increase the effectiveness of fracturing, as witness most of the papers at this meeting.

In spite of the tremendous effort to take advantage of fracturing, the origin of natural fractures is still considered "controversial." I will show in this presentation that natural fractures and related joints arise from small to moderate movements on basement faults, that basement faults with such small movement are not mappable by the common techniques used in exploration, i.e. subsurface geology and seismic methods, and hence with no basement faults to compare to, the basement connection has been missed and thus has not been exploited. I will then show that magnetic methods, properly used, readily and clearly map the basement faults, and that these faults always coincide in direction with natural fractures, many times coincide in location with natural fractures, and that natural fracturing is particularly enhanced at the intersections of basement faults.

I will also show that studies used to prove a connection of natural fractures with folding of sedimentary rocks are probably correlating only because fractures and folds alike arise from the same underlying faults, fractures being second generation reactivation features and folds being third generation reactivation features. These relationships are explained in the accompanying "Basement Inheritance Chart."

Presented at Annual GSA Meeting
Denver, Colorado, 27 October 2002

Some Important Consequences of Reactivation Tectonics:
New Geological Principles Discovered

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ABSTRACT

In a previous GSA talk (1999 Annual mtg), the writer showed conclusive evidence that most faulting within U.S. sedimentary basins results from reactivation of pre-existing shear zones in the underlying Precambrian basement. This conclusion was amply proven by hundreds of correlations of aeromagnetically-mapped basement faults/shear zones with faults, folds, fracture zones and stratigraphic features in the overlying sedimentary section, documented by detailed petroleum industry subsurface and seismic data in 21 U.S. sedimentary basins. If this correlation is true for basins, then it applies to cover rocks overlying cratons everywhere. The consequences of this finding are profound and far-reaching, and I will present three examples of the type of geologic advances that can result from an understanding of reactivation tectonics:

No. 1) Anticlines are the most common, and most studied, geological structures, after faults, that we know of, and most geologists would say there is little more we can learn about their formation. Yet there is an important characteristic of anticlines not usually considered - longitudinal closure. We acknowledge transverse closure due to transverse shortening, but we neglect shortening that occurs along the long axis of the anticline. I will show, by resolution of stress vectors, that this longitudinal shortening <u>must result</u> from reactivation of a causative underlying basement fault <u>not at right angles to maximum compressive stress</u>. In fact, as the strike of the underlying fault departs more and more from this angle, the anticline becomes less elongated until at approximately 45° it becomes dome-shaped. Enigmatic **compressional domes** are therefore explained by this mechanism.

No. 2) Side-stepping fault systems are infrequently recognized on geology maps but appear to be <u>common</u> in compressive structural regimes. They occur when faults or folds are formed in areas where a set of parallel basement faults is not at right angles to maximum compressive stress.

No. 3) Jointing of sedimentary rocks is a phenomenon that has never been completely and satisfactorily understood since joints were first mapped by geologists in the 1800's. However, the occurrence of sets of parallel joints over wide regions is readily explained by meter-scale reactivation of <u>sets of pervasive, parallel basement faults</u>.

Presented at: 17th Intl Basement Tectonics Conference
June 2004, Oak Ridge, TN

OLD & NEW ADVANCES IN BASEMENT REACTIVATION TECTONICS

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ABSTRACT

Basement shear zones, as observed with surface mapping and on Landsat and radar images of outcropping basement on all the world's shields, occur pervasively in parallel sets on the cratons and cut the crust into a series of separate blocks. The bounding shear zones become reactivated in subsequent tectonic events or by later sedimentary or tectonic loading. In sedimentary basins, the underlying shear zones and basement blocks are not visible at the surface, of course, but can be mapped by properly flown and processed aeromagnetic data down to at least 5 km depth.

In 1972 I obtained one-on-one correlations in the Paradox Basin between basement shear zones mapped with aeromagnetics and 1) R. A. Hodgson's classic study of jointing and 2) with Vincent Kelly's map of the Comb Ridge monocline. This work proved to me that basement shear zones controlled the Pennsylvanian-aged monoclines and were also responsible for the original joint pattern. In the subsequent 32 years I have mapped basement faults in basins throughout the U.S. and compared them to the locations of hundreds of reliably mapped known faults and stratigraphic features in the sedimentary section. From this work I can state definitively that most faults in the sedimentary section (excluding thin-skinned thrusts and growth faults) are reactivated basement faults, and that many, perhaps the majority of, stratigraphic features arise from lesser movements of these basement faults. Reactivation tectonics, thus, is that discipline of geology, which explains how structures and stratigraphic features observed in younger rocks are many times inherited from faulting of underlying older rocks, usually basement.

This work has also resulted in explanations of some very common geological features that we thought were well understood, but weren't, such as anticlines, and others we've never had a good explanation for, such as structural domes. Anticlines are nearly always asymmetrical in cross-section, and arise from compression across underlying reverse faults. They are thus shortened in the transverse direction. However, they are also shortened in the longitudinal direction, resulting in 4-way closure. This comes about because the causative underlying reverse faults are pre-existing basement faults whose strike is not necessarily at right angles to maximum compressive stress, so there is a component of strike-slip movement, as I will explain. A structural dome (as opposed to salt domes or compactional domes over underlying topography), can result when the angle between the underlying fault and maximum compressive stress varies a considerable amount from 90º. These findings are new.

Another geological situation, also not fully understood, is the occurrence of side-stepping systems of faults, many times confused with en-echelon faults, but more often unrecognized. These result when a series of parallel basement faults are reactivated in strike-slip fashion by maximum compressive stress not at right angles to the faults. Examples will be shown.

Another of the important aspects of geology that is explained by reactivation tectonics is the connection between jointing, fracturing, lineaments and linears, the latter two being subjects that, to this day, in spite of their ubiquity, have not been properly understood. The very straightforward connection of these features to basement faulting that I will show should dispense with that problem.