PORE PRESSURE THROUGH EARTH MECHANICAL SYSTEMS pdf

1: Subsurface stress and pore pressure -

Get this from a library! Pore pressure through Earth's mechanical systems: the force balanced physics of the Earth's sedimentary crust. [Philip William Holbrook].

Because pore pressure and horizontal stresses are interrelated, changes in pore pressure also cause similar changes in stress. While the exact relationship depends on the properties of the reservoir, it is reasonable to assume that the change in horizontal stress is approximately two-thirds of the change in pore pressure see Eq. This leads to a considerable reduction in leakoff pressure in a depleted reservoir and an increase in horizontal stress where pore pressure increases. It is important to note that Eq. Effective stress The mathematical relationship between stress and pore pressure is defined in terms of effective stress. Implicitly, the effective stress is that portion of the external load of total stress that is carried by the rock itself. The concept was first applied to the behavior of soils subjected to both externally applied stresses and pore pressure acting within the pore volume in a paper by Terzaghi [3] as This reduces the effective stress law to its original form Eq. When expanded, the Terzaghi effective stress law becomes and Because these properties vary with effective stress, it is therefore possible to determine the effective stress from measurements of physical properties such as velocity or resistivity. This is the basis for most pore-pressure-prediction algorithms. At the same time, effective stress governs the frictional strength of faults and the permeability of fractures. Constraints on stress magnitudes If rock were infinitely strong and contained no flaws, stresses in the crust could, in theory, achieve any value. However, faults and fractures exist at all scales, and these will slip if the stress difference gets too large. Even intact rock is limited in its ability to sustain stress differences. It is possible to take advantage of these limits when defining a geomechanical model for a field when other data are not available. Stress constraints owing to frictional strength One concept that is very useful in considering stress magnitudes at depth is frictional strength of the crust and the correlative observation that, in many areas of the world, the state of stress in the crust is in equilibrium with its frictional strength. This concept is schematically illustrated in Figs. In the upper part of the figure, a series of randomly oriented fractures and faults is shown. Because this is a two-dimensional 2D illustration for simplicity , it is easiest to consider this sketch as a map view of vertical strike-slip faults. Once that happens, further stress increases are not possible, and this subset of faults becomes critically stressed i. The lower part of the figure illustrates using a three-dimensional 3D Mohr diagram, the equivalent 3D case. The fractures and faults shown in gray are optimally oriented to slip in the current stress field courtesy GeoMechanics Intl. The frictional strength of faults can be described in terms of the Coulomb criterion, which states that faults will slip if the ratio of shear to effective normal stress exceeds the coefficient of sliding friction i. Because for essentially all rocks except some shales 0. This is graphically illustrated using a 3D Mohr diagram as shown in the lower part of Fig. A 3D Mohr diagram plots three half circles the endpoints of which lie at values equal to the principal stresses and the radii of which are equal to the principal stress differences divided by 2. Planes of any orientation plot within and along the edges of the region between the circles at a position corresponding to the values of the shear and normal stresses resolved on the planes. The critically stressed light gray faults in the upper part of the figure correspond to the points also shown in light gray in the Mohr diagram, which have ratios of shear to effective normal stress between 0. The values of S1 and S3 corresponding to the situation illustrated in Fig. Numerous in-situ stress measurements have demonstrated that the crust is in frictional equilibrium in many locations around the world Fig. Regardless of whether the state of stress in a given sedimentary basin reflects the frictional strength of pre-existing faults, the importance of the concept illustrated in Fig. The in-situ effective stress ratio can never be larger than this limiting ratio. Therefore, all possible stress states must obey the relationship that the effective stress ratios must lie between 1 and the limit defined by fault slip as shown in Eq. These figures are constructed as plots at a single depth of SHmax vs. The shaded region is the range of allowable values of these stresses. The third region is constrained by the difference in the horizontal stress magnitudes [i. It is a plot of SHmax vs. SHmin as constrained by the strength of well-oriented, pre-existing faults. The limits are constrained by Eq. It is important to emphasize that the stress limit defined by frictional faulting theory is just thatâ€”a limitâ€”and provides a constraint only. The stress state can be anywhere within and along the boundary of the stress polygon. As discussed at length later, the techniques used for quantifying in-situ stress magnitudes are not model based, but instead depend on measurements, calculations, and direct observations of wellbore failure in already-drilled wells in the region of interest. These techniques have proved to be sufficiently robust that they can be used to make accurate predictions of wellbore failure and determination of the steps needed to prevent failure with a reasonable degree of confidence. Stress constraints owing to shear-enhanced compaction In weak, young sediments, compaction begins to occur before the stress difference is large enough to reach frictional equilibrium. Therefore, rather than being at the limit constrained by the frictional strength of faults, the stresses will be in equilibrium with the compaction state of the material. Specifically, the porosity and stress state will be in equilibrium and lie along a compactional end cap. The physics of this process is discussed in Rock properties Constraints, based on compaction, define another stress polygon similar to the one shown in Fig. It is likely that in regions such as the Gulf of Mexico, and in younger sediments worldwide where compaction is the predominant mode of deformation, this is the current in-situ condition. Also, it is important to apply end-cap analyses only where materials lie along a compaction curve, and not to apply these models to overcompacted or diagenetically modified rocks. If the material lies anywhere inside the region bounded by its porosity-controlled end cap, this constraint can be used only to provide a limit on stress differences.

2: The Force-Balanced Companies

"Pore Pressure through Earth Mechanical Systems" is a constitutive field theory that relates compactional strain to composition in the earth. Minerals and fluids are the dominant natural molecular matter in the earth.

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The essays in the adjoining News webpage are also reflect current mechanical understanding and a higher level of science. Let the balanced forces and natural energy minimization be with you. It also explains the deterministic relationships between macro-mechanics and fundamental atomic and molecular structures. A glossary of technical terms is included at the end of the book. It defines "Deterministic" and most of the other terms that are related. This was a medium length technical paper that covers the direct mechanical applications. It is no longer available over the internet, but you may be able to get a copy through Walter Marlowe. Holbrook, P W, a Chapter 3 , "The primary controls over sediment compaction. Holbrook, P W, b Chapter 14 , " Method for determining regional force balanced loading and un-loading pore pressure regimes and applying them in well planning and real-time drilling", pp. This book explains how the scalar pore pressure is related to overall natural force balance. It encompasses the two AAPG articles immediately above in its contents. The molecular scale causal relationships that support this macro-mechanics are in the book. A glossary of technical terms is included at the end of each book. The journal version of this article is copyrighted. This is a pdf file that is KB in size and will need to be opened with an Adobe Acrobat browser. Click on Deep Water to hyperlink to this location on this website. This is a pdf file KB in size and will need to be opened with an adobe acrobat browser. Holbrook, P W, d, " Method for determining regional force balanced loading and un-loading pore pressure regimes and applying them in well planning and real-time drilling", in Pressure Regimes in Sedimentary Basins and their Prediction, AADE Industry forum proceedings, September 1 - 4, Del Lago, Texas. Goldberg, I, and B. Dissertation, The Pennsylvania State University, p. Patent 5,, Holbrook, P W, H Robertson, and M Hauck, , "Method for determining pore pressure and horizontal effective stress from overburden and effective vertical stress", U. Civil engineering and soil mechanics scientists have been creating and testing small scale constitutive mechanical models for decades. Deterministic earth mechanics is an earth encompassing field theory. Stresses and fluid pressure are contributing parts of the two-phase continuous field. Minerals, fluids and gasses are minimum energy forms of matter at earthly pressures and temperatures. Mineral and fluid molecules interact with their nearest neighbor through interactions between their contiguous electron clouds. Stress ratios in each of three tectonic regimes center about one of three local energy minima. Each energy minimum predicts the overburden relative magnitudes of the principal stresses. Overburden is an accompanying real numbered scaling factor. Each of three equation matrices describes a ratio of vectorial forces that is limited by the same scalar force balance. Each matrix has the same single line definition of strain, gravity, and scalar force balance. Each matrix has a different set of vectorial stress ratios that are symmetrical about the scalar effective stress. Plastic compaction depends on the average mineralogy of a sedimentary rock. These have been measured in the laboratory and in the earth. Overburden, pore fluid pressure, fracture propagation pressure, average mineralogy and porosity are related in a closed-form mechanical system. Fracture propagation pressure and capillary pressure are the proximal limits of pore fluid pressure. They are components of a comprehensive force balance. Petrophysicists can make accurate mechanical predictions using their expertise at estimating average mineralogy and porosity. Most often the observed levels of effective stresses and pore fluid pressures are close to that predicted by the local energy minimum. The earth is an accurate two part pressure and strain gauge. One needs its mechanical coefficients to read it. These have been established empirically. Mechanical predictions can be made deterministically ahead of the bit. The same mechanical model predicts in remote locations so long as the tectonic regime is the same. Reflection seismic signals follow elastic constitutive physics. The most likely pressure and stress predictions are the local energy minimum. The mechanical energy in minerals, fluids, and gasses depends on the configuration of nuclear centered electron clouds. All nuclear centered electron clouds have soft spherical symmetry. Spherical symmetry and composition control the bulk moduli of minerals, fluids, and gasses. The bulk and shear moduli of the common minerals can be found in handbooks Carmichael, R. Fluids and gasses have only bulk moduli that are explained by equations of state. Archer described the eos for the most abundant earth fluid, Sodium Chloride brine. A simple lever rule governs the elastic behavior of natural earth materials Holbrook, PW, The weighted average of the fluid and gas bulk moduli in a sedimentary deposit is the intercept point on the Vp2 axis of figure 1. The weighted average of the minerals that compose the grain matrix resolve to another end point on the Vp2 vs. Rock and fluid moduli are end points of this lever which is linear on Vp2 vs. The Gassmann and Hashin-Schtrictman symmetrical pore models apply in the absence of systematic fractures. These equations also apply parallel to systemic fractures joints that tend to polarize shear waves. These equations do not work across major shear fractures i. The figure is colorized version of figure 5. Vp2 and Vs2 depend primarily on bulk mineralogy and porosity of a sedimentary rock. This is a near complete description of rock static elastic properties. The box in figure 1 shows the range of clay elastic moduli from Hashin-Schtrikman decomposition. Claystones fail at very low stresses as well. In claystones acoustic disturbances must pass through fluid electron clouds to reach the next solid electron cloud. At lower porosities their response is quasi-linear on the Vp2 vs. Compactional strain is directly proportional to solidity in agreement with the law of solid mass conservation figure 2 right. Solidity is the mathematical complement of porosity that has a distinct upper limit. Effective stress solid partitioned energy is power-law proportional solidity solid mass conserved strain taken from figure 9. Each of the regression lines on figure 2 covers a wide porosity range. These are near surface effects at effective stresses below psi. Anhydrite and Halite are late stage evaporites from sodium chloride rich brines. Their porosity reduction is complete at less than psi. Thereafter salt behavior becomes entirely plastic forming natural salt pillows, ridges, and domes. Most mineral grains including Quartz, Calcite, Halite, and Anhydrite have electrostatically neutral grain surfaces. The broad surfaces of clay minerals have negatively charged oxygen anions at their particle surfaces. Thus clay minerals have a net negative surface charge. Compaction resistance is the sum of inter- and intra-particle repulsions Holbrook, P. Clays have additional inter-particle repulsion. Particles with net neutral surface charge have no net inter-particle repulsion. Grains of quartz and calcite immediately come in direct contact forming a granular solid at near zero effective stress. Both are inverse square laws that affect atoms and ions. That hypothesis is a dimensionally correct summation of accepted physical laws. Energy is conserved in each of these physical laws and in the synthesized law hypothesis. The mechanical energy associated with gasses and fluids is pore pressure. The energy associated with solids is effective stress. The effective stress theorem provides that the sum of solid and fluid energy is conserved. Energy conservation is typical of physical laws.

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3: - Pore Pressure through Earth Mechanical Systems by Phil Holbrook

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Fellow Earth Scientists, The earth is principally composed of natural minerals and fluids. The physical-mathematical result is the unified earth mechanical system. The static effective stress theorem applies everywhere. Each plane is a minimum energy convergence of physical laws and stresses with physical properties strain. The colored lines on this plane are power-law mineral specific compaction functions. A rock is the scalar weighted average of its mineralogy. Upper right All loading and unloading occurs within the mineral specific plastic and elastic limits. The limbs hinge at the peak loading-limb point. Lower left Vectorial stresses are conserved within scalar. They equilibrate at minimum energy. Center right The mineral specific elastic functions lie along a mineral-fluid lever. Lower right The failure envelopes of sedimentary rocks depend upon maximum and minimum principal stresses. The angle of internal friction is a function of scalar average mineralogy. For each tectonic regime the stresses are represented by the scalar and vectorial stresses shown on the lower left. These tend toward deterministic minimum energy ratios. The borehole schematic below shows the interdependent scalars and vectors in the normal and strike-slip tectonic regimes. The balance of forces in the earth has scores of practical subsurface mechanical engineering applications. Pore pressure Fracture pressure and overburden are the three primal forces in the earth. Natural minerals and fluids generate and bear the forces in the earth symmetrically. In addition to the exposition of significant new science, the newer book honors the most significant scientific contributors to the present level of the Deterministic Sciences. A small set of physical laws work through the constituents of the earth. The principles of deterministic science were established by Isaac Newton. This set a very high standard for subsequent scientists to follow. An additional small set of physical laws describe how molecular electron clouds repel each other. Gravity is balanced by molecular electrostatic repulsion in the earth. These laws were first explained by Charles Augustin Coulomb in This book also fills the physical-logical gap between Newtonian and Quantum mechanics. Natural mineral and fluid molecules are the working units of earth mechanics. Both books synthesize the mechanical laws of Newton, Coulomb, and Hooke. Both mechanical explanations are supported by the same minimalist constitutive mechanical system theory. These two books are a significant advancement in physics through their revelation of earthly molecular mechanics. Earth mechanics are completely scalable from molecular electron clouds which affect borehole walls in basins on drifting continental plates. The Venn diagram below illustrates the overlapping characteristics of physical, and inorganic chemical laws with deterministic earth mechanics. The common pattern of the deterministic sciences will be revealed and explained in a newer book but can be taught now. The dashed lines extending outward symbolize direct algebraic connections to essential physical laws. The whole diagram represents physical realities that have been discovered in nature. The other two tectonic regime specific equation matrices are in "Deterministic Earth Mechanical Science. Either " Pore Pressure through Earth Mechanical Systems " or " Deterministic Earth Mechanical Science " can be ordered by phone, through book distributors or over the internet. A book synopsis and table of contents can be seen by clicking on either of the book titles that are highlighted blue. Each book includes a glossary of technical terms. Years of work were involved in study and preparation. The books are modestly priced for maximum educational benefit. Hardbound copies are much more durable and only a little bit more expensive.

4: Coupled pore fluid diffusion and stress analysis

Pore Pressure through Earth Mechanical Systems: the Force Balanced Physics of the Earth's Sedimentary Crust by Phil Holbrook. Force Balanced Publications,

Soil mechanics problems generally involve fully saturated flow, since the solid is fully saturated with ground water. Typical examples of saturated flow include consolidation of soils under foundations and excavation of tunnels in saturated soil. Partially saturated flow occurs when the wetting liquid is absorbed into or exsorbed from the medium by capillary action. Irrigation and hydrology problems generally include partially saturated flow. Combined fully saturated and partially saturated flow occurs in problems such as seepage of water through an earth dam, where the position of the phreatic surface the boundary between fully saturated and partially saturated soil is of interest. These problems may involve partially saturated flow in polymeric materials such as paper towels and sponge-like materials; in the biomedical industry they may also involve saturated flow in hydrated soft tissues. The porous medium modeling provided considers the presence of two fluids in the medium. Often the other is a gas, which is relatively compressible. An example of such a system is soil containing ground water. When the medium is partially saturated, both fluids exist at a point; when it is fully saturated, the voids are completely filled with the wetting liquid. The elementary volume, , is made up of a volume of grains of solid material, ; a volume of voids, ; and a volume of wetting liquid, , that is free to move through the medium if driven. In some systems for example, systems containing particles that absorb the wetting liquid and swell in the process there may also be a significant volume of trapped wetting liquid,. The porous medium is modeled by attaching the finite element mesh to the solid phase; fluid can flow through this mesh. The model also uses a continuity equation for the mass of wetting fluid in a unit volume of the medium. The conjugate flux variable is the volumetric flow rate at the node,. The porous medium is partially saturated when the pore liquid pressure, , is negative. The excess pore fluid pressure at a point is the pore fluid pressure in excess of the hydrostatic pressure required to support the weight of pore fluid above the elevation of the material point. Total pore pressure solutions are provided when the gravity distributed load is used to define the gravity load on the model. Excess pore pressure solutions are provided in all other cases; for example, when gravity loading is defined with body force distributed loads. Thus, for example, thermal expansion of the liquid phase has no effect on the steady-state solution: Therefore, the time scale chosen during steady-state analysis is relevant only to rate effects in the constitutive model used for the porous medium excluding creep and viscoelasticity, which are disabled in steady-state analysis. Mechanical loads and boundary conditions can be changed gradually over the step by referring to an amplitude curve to accommodate possible geometric nonlinearities in the response.

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