possible to account for virtually all of the paleomagnetically indicated rotations in pre-Miocene Tertiary rocks of the Pacific Northwest by an extensional tectonic model. As a consequence, only part of the rotations in the pre-Tertiary rocks of the eastern Columbia Embayment need to be the result of accretionary tectonics. The initiation of magmatism in the eastern Columbia Embayment that is represented by the Clarno Formation itself may have been contemporaneous with the beginning of crustal extension in the Pacific Northwest.
J. Geophys. Res., B, Paper 6B5949

1540 Rock and mineral magnetism
Paleomagnetism of red cherts: A case study in Inuyama area, Central Japan
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S. Sasajima

This study is an attempt to isolate and identify the primary magnetization in red cherts. Red chert samples from a middle Triassic sequence in the Inuyama area (35.4°N, 137.0°E), central Japan have a multicomponent magnetization, which is delineated by thermal demagnetization. Two of the components have high coercivity and high blocking temperatures; one is carried by hematite and the other by magnetite. The former was concluded to be the primary magnetization for two reasons; 1) it predates intra-formational folding, 2) it records geomagnetic reversals. The other component, which accounts for the dominant part of NRM, was probably acquired at a time long after the deposition. Two paleomagnetic results were drawn from the Middle Triassic red chert sequence: 1) The mean inclination of the samples in the sequence was 1.4°±6.8°. Therefore, the paleolatitude amounts to 0.7°±3.4°, in contrast to the paleolatitude expected from the paleopole of Eurasian continent, which is about 70°. 2) The magnetostratigraphy of this sequence indicates that two geomagnetic epochs in the Middle Triassic are considerably longer (more than several million years) than the average of those in the Cenozoic. (Multicomponent magnetization, accretion tectonics, reversal frequency.)
J. Geophys. Res., B, Paper 6B5928

1599 General Paleomagnetism
PALEOMAGNETIC DIRECTIONAL DISPERSION PRODUCED BY PLASTIC DEFORMATION IN A THICK MIOCENE WELDED TUFF, SOUTHERN NEVADA: IMPLICATIONS FOR WELDING TEMPERATURES
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Two voluminous ash-flow sheets, the Tiva Canyon and Topopah Spring Members of the Paintbursh Tuff, were erupted from the Claim Canyon cauldron. Although lithologically similar, these units differ greatly in their recording of the ancient geomagnetic field. the reversely magnetized Tiva Canyon Member yields remanent directions that are well grouped both within and between sites. The normally magnetized Topopah Spring Member, however, yields remanent directions that vary both laterally and vertically. Remanent directions from a 100-m-thick section of nonwelded to partially welded Topopah Spring are well grouped (precision parameter, k>200) and give a mean direction (D=293°, I=69°) that is probably a good approximation of the geomagnetic field at the time of cooling. In three ~300 m thick sections of more densely welded tuff, inclinations from the upper parts of the Topopah Spring are steep (~70°), but flatten with depth to about 20°, and then steepen abruptly near the base of the unit. In general, the directional dispersion increases with the thickness of the section (k~30 for sections that are about 300 m thick). Much of the directional variation in the Topopah Spring can be attributed to an inclination error produced by sub-blocking temperature rotation of the magnetic carriers during welding. The possibility of sub-blocking temperature deformation in an ash-flow sheet is enhanced by (1) high-blocking temperature spectra of the primary magnetic phases, (2) relatively low emplacement temperatures, and (3) great stratigraphic thickness. Thermal demagnetization results from the Topopah Spring Member indicate that welding may have continued to temperatures as low as 475°C in the basal vitrophyre of the ash-flow sheet. Remanent directions from the Tiva Canyon Member were unaffected by the welding process, because this unit possesses significantly lower blocking temperatures and does not attain the great thicknesses of the Topopah Spring. (Paleomagnetism, directional dispersion, ash-flow tuff, welding.)
J. Geophys. Res., B, Paper 6B6002

of investigating borehole and disc permeameters in unsaturated anisotropic soils. (Unsaturated flow, anisotropy, subirrigation, field permeameters.)
Water Resour. Res., Paper 6W4495

1872 Transport
STREAMLINE ROUTING THROUGH FRACTURE JUNCTIONS
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Karen M. Koslow

A series of laboratory tests was conducted to determine routing criteria for streamlines through fracture junctions. These tests showed that two criteria are all that is necessary to route streamlines through any two-dimensional junction under laminar flow conditions. These criteria are 1.) that streamlines do not cross; and 2.) that flow along adjacent streamlines must be in the same direction. Using these two criteria, a unique distribution of streamlines can be determined for both continuous and discontinuous fracture junctions. (Transport, groundwater.)
Water Resour. Res., Paper 6W4510

1830 Groundwater
CHLORINE-36 DATING OF VERY OLD GROUND WATER: 1. THE GREAT ARTESIAN BASIN, AUSTRALIA
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Fred M. Phillips, Stanley N. Davis, M. A. Habermehl, Peter L. Airey, Graeme E. Calf, David Elmore, Harry E. Gove, and Thomas Torgersen

Chlorine-36 has many advantages as a dating tool for very old ground water. These advantages include a suitable half-life (3.01×10^5 years), simple geochemistry, conservative behavior in ground water, and a general absence of subsurface sources at levels comparable to the atmospheric input. Recent advances in tandem-accelerator mass spectrometry have permitted the analysis of ^{36}Cl at the low abundance expected following residence in the subsurface for 10^6 years or more. In order to test the suitability of ^{36}Cl for dating very old ground water, the $^{36}Cl/Cl$ ratios of 26 ground-water samples from the Great Artesian Basin of Australia have been measured. Ground-water ages calculated from the ^{36}Cl data compare favorably with ages computed independently from hydrodynamic simulations. (Groundwater, radiometric dating, tracers, chlorine-36.)
Water Resour. Res., Paper 6W4352

1830 Groundwater
THE INVERSE PROBLEM FOR CONFINED AQUIFER FLOW: IDENTIFICATION AND ESTIMATION WITH EXTENSIONS
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The contributions of this work are twofold: (1) A methodology for estimating the elements of parameter matrices in the governing equation of flow in a confined aquifer is developed. The estimation techniques for the distributed-parameter inverse problem pertain to linear least-squares and generalized least-squares methods. The linear relationship among the known heads and unknown parameters of the flow equation provides the background for developing criteria for determining the identifiability status of unknown parameters. Under conditions of exact- or over-identification it is possible to develop statistically consistent parameter estimators and their asymptotic distributions. The estimation techniques, namely, two-stage least squares and three-stage least squares, are applied to a specific groundwater inverse problem, and compared among themselves and with an ordinary least-squares estimator. The three-stage estimator provides the closer approximation to the actual parameter values, but it also shows relatively large standard errors as compared to the ordinary and two-stage estimators. The estimation techniques provide the parameter matrices required to simulate the unsteady groundwater flow equation. (2) A nonlinear maximum likelihood estimation approach to the inverse problem is presented. The statistical properties of maximum likelihood estimators are derived, and a procedure to construct confidence intervals and do hypothesis testing is given. The relative merits of the linear and maximum likelihood estimators are analyzed. Other topics relevant to the identification and estimation methodologies, i.e., a continuous time solution to the flow equation, coping with noise-corrupted head measurements, and extension of the developed theory to nonlinear cases are also discussed. A simulation study is used to evaluate the methods developed in this study. (Groundwater flow, parameter identification, least-squares estimation, maximum likelihood estimators.)
Water Resour. Res., Paper 5W4320

1830 Groundwater
A THREE-DIMENSIONAL FINITE ELEMENT MODEL FOR SIMULATING WATER FLOW IN VARIABLY SATURATED POROUS MEDIA
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E.P. Springer, V. Guvanasen, T.D. Wadsworth

A three-dimensional finite element model for simulating water flow in variably saturated porous media is presented. The model formulation is general and capable of accommodating complex boundary conditions associated with seepage faces and infiltration or evaporation on the soil surface. Included in this formulation is an improved Picard algorithm designed to cope with severely nonlinear soil moisture relations. The algorithm is formulated for both rectangular and triangular prism elements. The element matrices are evaluated using an "influence coefficient" technique that avoids costly numerical integration. Spatial discretization of a three-dimensional region is performed using a vertical slicing approach designed to accommodate complex geometry with irregular boundaries, layering, and/or lateral discontinuities. Matrix solution is achieved using a slice successive over-relaxation (SSOR) scheme that permits a fairly large number of nodal unknowns (on the order of several thousand) to be handled efficiently on small minicomputers. Six examples are presented to verify and demonstrate the utility of the proposed finite element model. The first four examples concern one- and two-dimensional flow problems used as sample problems to benchmark the code. The remaining examples concern three-dimensional problems. These problems are used to illustrate the performance of the proposed algorithm in three-dimensional situations involving seepage faces and anisotropic soil media. (Groundwater, soil, infiltration, finite element modeling.)
Water Resour. Res., Paper 6W4622

1869 Hydrology
NUMERICAL ESTIMATION OF EFFECTIVE PERMEABILITY IN SAND-SHALE FORMATIONS
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A numerical approach is used to estimate effective permeability in sand-shale formations under saturated steady-state uniform flow conditions. Permeability is modeled as a binary, second-order stationary random process taking on two possible values, K_{ss} and K_{sh} in sandstone and shale respectively. Experience with sandstone reservoirs indicates that randomly dispersed low-permeability shales are the dominant heterogeneity affecting flow behaviour. The model is applied to data from the Assakao sandstone which outcrops in the Tassili region of the central Sahara. The Turning Bands method is used to simulate the spatially correlated permeabilities of finite-difference grid blocks discretizing a parallelepipedic flow field. Calculated effective permeabilities are found to depend on the shale volume fraction and the spatial covariance structure. Existing analytical methods for estimating effective permeability are shown to be inaccurate when compared to numerical results or inapplicable to stratified environments. (Stochastic model, heterogeneous porous media, effective permeability.)
Water Resour. Res., Paper 5W4239

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