Na_2O (factors to 0.1), Rb (to 0.3), Sr (to 0.3), and Ba (to 0.1) and enrichment in S (to 10), Fe (to 10), Zn (to 5) and As (to 5), presumably reflecting hydrothermal leaching and deposition of pyrite. The occurrence of igneous compositions near the contact and the preservation of obsidian at the contact requires that only minor syn- or post-emplacement hydrothermal activity occurred there.

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Structural Events and Influences in the Development of the Valles-Toledo Caldera Complex

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Volcanism in the Jemez volcanic field of north-central New Mexico culminated with two famous caldera forming episodes: the nested Toledo (1.5 Ma) and Valles (1.13 Ma) calderas. In addition, new work suggests an earlier, smaller caldera formed in the same area at probably about 1.78 Ma. All three caldera cycles yielded compositionally similar tuffs. It has been recognized for some time that northeast-trending regional structures have controlled gross caldera complex collapse structure. Stratigraphic studies of intracauldron tuffs indicate that, indeed, each of the three calderas exhibits influences of this northeastern structural grain, as well as ring fracture faulting, on collapse structure in the western half of the complex. Bedding indicators in scientific core holes near the west flank of the Valles caldera's resurgent dome show constant dips of units throughout intracauldron tuffs of all three caldera cycles as well as in pre-caldera units. This means that of three spatially coincident calderas, only the youngest, the Valles caldera, experienced structural doming during resurgence. Work of others appears to constrain the structural doming event to within 100,000 years of caldera formation. In this same period, hydrothermal activity was established, and a huge canyon, breaching the caldera, was incised greater than 300 meters. In the core holes, most faults and fractures, constituting the major hydrothermal conduits, are predominantly low angle (less than 60 degrees), suggesting their genesis during listric faulting and possibly slumping in the structural doming event. At around 500 ka, a probable major tectonic event on a pre-caldera structure caused changes in base level of the major canyon draining the caldera, which in turn caused changes in configuration of the hydrothermal system, perturbation in hydrothermal outflow, and aggradation in the caldera breach.

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2.5 Ma Ash-Flow Caldera at Chegem River in the Northern Caucasus Mountains (USSR), Associated Mineralization, and Drill-hole Data from Contemporaneous Granite

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Diverse latest Pliocene volcanic and plutonic rocks in the north-central Caucasus Mountains are interpreted as parts of a unified large magmatic system that erupted a 2.5 Ma zoned rhyolitic-dacitic ash-flow sheet. Preserved remnants of the outflow tuff sheet extend at least 40 km north from a source caldera in the upper Chegem River. The 11x15 km caldera and associated intrusions are superbly exposed over a vertical range of 2,300 m in deep canyons above treeline (elev. to 3,800 m). The single cooling unit of densely welded intracaldera tuff, previously described by others as a rhyolite (liparite) lava plateau, is >1.5 km thick and contains large slide blocks from the caldera walls. No caldera floor is exposed. The caldera-filling tuff is overlain by andesitic lavas and cut by a granite porphyry intrusion that has a cooling age contemporaneous with the tuffs, and with roof levels of the Eldjurata Granite exposed in the next large canyon (Baksan River) 10 km to the northwest. Biotite K-Ar ages decrease inward and downard (2.5 to 1.5 Ma) for surface and drillhole samples from as deep as 2.4 km within the Eldjurata Granite (Gurbanov et al, 1990), recording mean cooling rates and thermal gradients within upper parts of a solidified caldera-related magma chamber. Major Mo-Wo ore deposits at the Tirniauz mine are hosted in scarns and hornfels along the roof of the Eldjurata Granite, and associated aplitic phases have textural features of Climax-type molybdenite porphyries in the western USA. Similar K-Ar ages, mineral chemistry, and bulk-rock compositions indicate that the Chegem tuffs and associated intrusions are parts of a large magmatic system that resembles the middle Tertiary Questa caldera system and associated Mo deposits in northern New Mexico, USA.

V21C-6 1015h INVITED

Strategies for Drilling and Logging in High-Temperature Formations

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The core drill and the logging tool are complimentary instruments used to obtain data from subsurface formations. Two deployment strategies are commonly used in scientific programs. One strategy is due to the coring technology developed in the Ocean Drilling Program (ODP). While this technology yields good core recovery in sediments or competent hardrock formations, recovery can be less than optimal if the formation is comminuted. Thus, the ODP system features an extensive suite of logs that augment imperfect core data. Since most logging tools are not designed for use in high-temperature environments, the ODP strategy is deficient for thermal regime efforts that encounter highly fractured rock. An alternate system is provided by diamond coring techniques that yield nearly 100% core recovery even in difficult formations. Therefore, an extensive logging suite is not needed and logs are used only to obtain data that cannot be obtained from core. Of importance to either system are measurements of the formation temperature and the sampling of formation fluids. While suitable tools are available, the attainment of information not perturbed by the coring operation itself posses a difficult problem.

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The Valles Caldera Hydrothermal System, New Mexico

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Valles caldera (1.13-0.13 Ma) contains a "type" example of an active, caldera-hosted hydrothermal system with many analogues to fossil systems. Surface features include acid-sulfate, thermal-meteoric, and neutral-chloride springs (≤95°C). Neutral-chloride reservoir fluids contain 2-20x10^3 TDS at 210-300°C. Hydrologic configuration consists of local meteoric recharge, slow percolation and heating at depths of 1-3 km, convective rise along faults in the resurgent dome area, and subsurface lateral outflow along faults cutting the caldera wall. A vapor-rich cap 500 m thick is sustained by subsurface boiling at the top of the underlying reservoir. Mean residence time of fluid circulation is between 3 and 10 ka. Alteration zones consist (top to bottom) of argillic, phyllic, propylitic, and calc-silicate assemblages. Vein minerals include Qtz, Cc, Ill, Chl, Py, Ep, Adul, Flu, and Wair and ore minerals include Cpy, Sphal, Gal, Moly, and Pyrar. Fluid inclusion (FI) studies show that most veins formed at temperatures similar to present. Salinities of FI's resemble those of present fluids. Modeling indicates that observed alteration assemblages and veins are compatible with present fluid compositions. Isotopic studies of altered rocks show strong interaction with meteoric water. Dating indicates the hydrothermal system formed ~1 Ma and has been continuously active to present. However, a variety of evidence indicates that the vapor zone formed ~0.5 Ma due to a rapid drop of the liquid-dominated reservoir. Some scientific issues to resolve are: 1. evidence for "blind" systems in undrilled sectors of the caldera; 2. evidence of present magmatic components in hydrothermal fluids; 3. characterization of hydrothermal interactions with Precambrian basement.

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Implications of $^{18}O/^{16}O$ and D/H Data on Hydrothermally-Altered Terranes to the Deep-Level and Long-Term Characteristics of Caldera-Related Hydrothermal Systems

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Eroded hydrothermally-altered terranes provide much information about the inaccessible deep levels and long-term characteristics of modern geothermal systems. Detailed isotopic maps of large (12 to 60 km dia.) Tertiary calderas in the Idaho batholith (Bull GSA, 94, 640-663) and in the Challis (Geology, 12, 331-334) and San Juan volcanic fields (J. Volc. Geotherm. Res., 30, 47-82) prove that 1) the ground-water circualtion pattern was affected over lateral distances of 50 km or more; 2) vertical ^{18}O gradients were produced in the crust, with fluid penetrating to depths of at least 5 to 10 km; 3) fluid temperatures were mostly 150° to 350°C; 4) isotopic disequilibrium between coexisting minerals was ubiquitous, consistent with system lifetimes of 10^5 to 10^6 years; 5) regional fluid/rock ratios were typically ~1, such that a large ^{18}O shift of the deep fluid occurs; and 6) the highest fluid-rock ratios (>>1), as integrated over the lifetimes of the systems, occurred along the ring fracture zones and adjacent to resurgent intrusions. Analogous zones in modern systems are clearly excellent drilling targets for geothermal resources.

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The Valles Hydrothermal System--A Caldera-Hosted, Modern Analogue of Creede-Type, Epithermal Silver/Base-Metal Systems

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The high-temperature hydrothermal system now circulating in the Quaternary Valles caldera complex is an active analogue of those which formed Creede-type, epithermal silver/base-metal ore deposits. The Valles and most Creede-type systems share the following attributes: 1) domination by neutral-chloride, high-temperature (200-300°C) meteoric waters, with overlying, steam-heated, H_2S- or CO_2-enriched waters derived by boiling of the neutral-chloride reservoir and condensation of the exsolved acid volatiles in locally-derived groundwaters; 2) focused fluid flow, principally along tectonic and hydrothermal fractures and breccia zones; 3) a magmatic heat source and temporal association with high-silica rhyolite volcanism; 4) deeper propylitic and quartz-sericite±adularia alteration with a high-level mixed-layer illite/smectite cap; 5) silver/base-metal mineralization. Pyrargyrite, for example, was discovered in Valles Continental Scientific Drilling Program (CSDP) corehole VC-2B (compl. 1988); argentiferous pyrite in a nearby geothermal well. Associated ore minerals include sphalerite, galena, and chalcopyrite. In spite of the listed similarities, no economic silver/base-metal mineralization has yet been discovered at Valles. This discrepancy has yet to be satisfactorily explained, but could reflect the different targeting strategies employed in geothermal and precious-metal exploration.

Valles CSDP corehole VC-2A (compl. 1986) penetrated an unusual, near-surface zone of low-temperature (200-230°C) molybdenite--a first in an active geothermal system. Since the active Valles system is clearly a Creede analogue, this discovery lends support to earlier suggestions that epithermal silver/base-metal mineralization may take place in the upper portions of Climax-type porphyry molybdenum systems.

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Comparisons of Oxygen Isotope Systematics of Fossil and Active Calderas: Bonanza, CO and Long Valley, CA

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Oxygen isotope studies of eroded calderas demonstrate that the locations of intrusions (heat and metal-bearing fluid sources) and of major permeability pathways control the circulation of hydrothermal fluids responsible for base- and precious-metals deposits. At reconstructed depths of ~2 km, O-isotope contours that surround the Oligocene Bonanza trapdoor caldera are smooth and attain the lowest values at the topographic caldera boundaries, near the inferred margins of subcaldera intrusions. At shallower levels, O-isotope contours are less regular and are more strongly influenced by zones of high permeability such as ring faults and intracaldera listric normal faults. Traverses across the western ring fault zone imply disturbances of earlier patterns by younger, rift-related normal faults. Systematically high $\delta^{18}O$ values at the NE caldera margin reflect O-exchange with magmatic fluids circulating beneath the caldera floor. Steep, reversed gradients in downhole O-isotope profiles imply that the Pb-Zn-Ag deposits at Bonanza formed when ascending magmatic fluids mixed with meteoric hydrothermal fluids circulating within the intracaldera tuff prism.

The deep fluid circulation patterns of active calderas are important to the geothermal industry, but are more difficult to evaluate from O-isotopic studies of surface rocks. In general, samples from deep boreholes must be analyzed to obtain information on deep fluid flow regimes. O-isotope profiles of eight wells within Long Valley caldera show that geothermal brines migrate laterally eastward for long distances and mix with cooler meteoric waters before they vent as springs or fumaroles and cause hydrothermal alteration of surface exposures. The patterns also indicate that hydrothermal alteration of Bishop Tuff deep beneath the resurgent dome probably occurred ~0.5 m.y. ago, during hydrothermal circulation unrelated to the current geothermal regime. The O-isotope profiles of Long Valley wells demonstrate that the current geothermal resource lies beneath the western moat of the caldera, where surface manifestations are quite subdued.