tion of stack ore. Virtually all zones of rock weakness are subjected to some mineralization near this front, and the sulfide-sulfate equilibria cause many of these stack deposits to resemble roll fronts. Roll geometry of some of this ore is due to encroachment of the front on reduced ground after the Laramide. Younger, but very local, solutions result in ore in oxidized ground, some of which is indicated by primary uranophane. Roll geometry is present for some of these deposits. The superimposition of the redox front on the older trend ore allows both carbon and sulfur to act as reductants, and orebody geometries are similar to Wyoming-type rolls in terms of uranium distribution but not necessarily for trace-element distribution.

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Periods of Mineralization in Grants Mineral Belt, New Mexico

Geologic observations coupled with laboratory studies indicate several periods of mineralization in the Grants mineral belt. The earliest mineralization is from trend ore in the Ambrosia Lake and Smith Lake districts; Rb-Sr radiometric ages on chlorite formed penecontemporaneously with primary uranium minerals range from 135 to 138 ± 8 m.y. This period of mineralization is within the limits of error for the age of sedimentation obtained on barren ground montmorillonite of 140 to 145 ± 10 m.y., but cross-cutting ore indicates early epigenetic as opposed to syngenetic mineralization. Early formed ore in the Laguna district was remobilized and reprecipitated during some mid-Cretaceous event at 110 to 115 m.y. determined on the basis of Rb-Sr dating. Ore was not derived from the overlying Dakota Formation (Cretaceous), as the Rb-Sr dates for the Dakota and Mancos formations are 92 ± 6 m.y. and 85 ± 10 m.y., respectively (in excellent agreement with U.S. Geological Survey K-Ar dating). Mineralization is present in the Dakota Sandstone, but whether the ore was syngenetic or epigenetic is unknown. Much of the stack ore was apparently formed during the Laramide orogeny about 60 m.y. ago, usually in close proximity to a redox front. Post-Laramide ore is proposed for several deposits in reduced ground at this redox front, some of which is apparently Tertiary although remobilized Jurassic ore cannot be distinguished from that from much younger sources even though reworked Jurassic ore is supported by high $^{87}Sr/^{86}Sr$ ratios. Ore possibly formed during the Tertiary from a southerly source for some deposits, and some remobilized ore, possibly of Pleistocene age, is common in minor amounts.

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Exploration in Grants Uranium Region Since 1963

The Grants uranium region is the largest uranium area in the United States. From 1951 through 1977, underground and open-pit mines produced 126,537 tons of uranium oxide U_3O_8. This amounts to 40% of the total United States uranium production. Ore reserves estimated by DOE for the region are 366,200 tons U_3O_8, or 53% of the domestic reserves in the $30 forward-cost category. Since 1963, production in the Grants uranium region has expanded to the north and east largely owing to the efforts of exploration programs of major oil companies. During this period, average drilling depths have increased from approximately 200 to nearly 1,600 ft (60 to 960 m). Application of various geologic models is expected to assist in finding additional deposits, and the Grants uranium region is expected to maintain its position as the nation's principal source of uranium for years.

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Geochemical Studies of Grants Mineral Belt, New Mexico

Several hundred clay mineral and whole rock samples of ores and barren rocks from the Grants mineral belt have been analyzed by instrumental neutron activation analysis (INAA) and delayed neutron activation analysis (DNAA). The DNAA method allows high precision and accuracy for uranium and thorium determination, whereas the INAA method allows determination of 20 to 30 trace elements. The trace-element data can only be interpreted properly if the clay-mineral (-2μ) fraction is compared directly with whole-rock samples. The INAA data support mineralization of trend ore as due to southeast-flowing solutions; the DNAA determination of uranium suggests that the source of uranium in the Westwater Canyon Member of the Jurassic was not from the overlying Brushy Basin Formation. Local zonation of trace elements, especially the rare earth elements (REE), indicates fixation of many trace elements when uranium mineralization occurred. Thus, REE-depleted, oxidized ground can, with caution, be used for exploration purposes. Vanadium originally precipitated as V^{3+} in chlorites remains in the original sites after oxidation to V^{5+} and is thus also valuable as a pathfinder. Data for antimony suggest that it, too, may be useful. In general, trend-ore deposits are characterized by a high chlorite + illite, illite + illite-montmorillonite, or illite + chlorite + illite-montmorillonite, whereas ore near the redox front may contain primary kaolinite. The REE are concentrated greatly in all types of ore, primary or secondary, and, coupled with uranium haloes, are useful as ore guides.

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Geology and Ore Deposits of Johnny M Mine, Ambrosia Lake District, New Mexico

The Johnny M mine is one of very few mines in the Ambrosia Lake district with uranium ore in two members of the Jurassic Morrison Formation; these members are the Westwater Canyon sandstone and the Brushy Basin shale. The Westwater Canyon ore is contained in the two upper sandstone units of the member, and the Brushy Basin ore is contained in the Poison Canyon sandstone.

The sedimentary features and structures in the Westwater Canyon sandstone indicate that the sediments