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IMPLICATIONS OF FISSION TRACK ANNEALING FOR GEOTHERMAL MODELS IN THE PACIFIC NORTHWEST

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by

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DISCLAIMER

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INTRODUCTION

The main objectives of this contract were twofold. The first was to develop and set up a fission track annealing/dating laboratory in the Department of Geological Sciences at Southern Methodist University, and to apply the results of data obtained in this laboratory to a variety of geological problems associated with geothermal systems (both regional and local) and to a lesser extent sedimentary basins. A second objective was to develop a model for the thermal effects of lateral fluid flow in geothermal systems and to combine the results from the fission track studies with the results from the analytical model. The combined results could be used to constrain the flow conditions using both measured temperature data and annealing data from apatite and zircon.

A total of seven publications have resulted from work supported completely or predominantly by this contract. Four of these papers have been published and three are in press at the present time. The titles are listed in Table 1. In addition, five talks were given at meetings for which abstract volumes were published and several additional talks were given at meetings for which no abstracts were published. Finally, contract funds were used to support all or part of the research for five M.S. or Ph.D. theses. All of the publications, abstracts, theses, and dissertations which have resulted from this contract are shown in Table 1. Included as part of this final report are copies of three published papers and one in press paper which document a major part of the research associated with this contract. As the results of the contract have been covered extensively in the literature only the briefest summary is given in this part of the report.

Table 1. Research publications from contract.

PUBLICATIONS

Blackwell, D.D., A transient model of the geothermal system of the Long Valley caldera, California, pp. 659-707, Proceedings of Workshop XIX, Active Tectonic and Magmatic Processes Beneath Long Valley Caldera, Eastern California, U.S. Geol. Surv. Open File Report 84-939, 1984.

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Kelley, S.A., and I.J. Duncan, Late Cretaceous to Middle Tertiary Tectonic history of the northern Rio Grande Rift, Jour. Geophys. Res., in press, 1985.

Ziagos, J.P., and D.D. Blackwell, A model for the transient temperature effects on horizontal fluid flow in geothermal systems, J. Vol. and Geoth. Res., in press, 1985.

ABSTRACTS

Blackwell, D.D., S.A. Kelley, and M. Reese, Fission track evidence on the late Cenozoic deformation of the Ruby Mountains Nevada, Geol. Soc. Amer. Abs. with Programs, 446, 1984.

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Bussey, S.D., Primary dispersion of Rb, Sr, and Ba around the Middle Mountain Molybdenum prospect, Chaffee County, M.S. Thesis, Southern Methodist University, Dallas, TX, 80pp, 1982.

Kelley, S.A., Fission-track annealing systematics in apatite with geological applications, Ph.D. Dissertation, Southern Methodist University, Dallas, TX, 210pp, 1984.

Sweetkind, D.S., Thermal histories of the Nelson batholith, southern British Columbia and the Idaho batholith, Idaho, M.S. Thesis, in preperation, Southern Methodist University, Dallas, Texas, 1985.

Ziagos, J.D., Theoretical and empirical terrestrial heat flow studies, Ph.D. Dissertation, Southern Methodist University, Dallas, TX, 142pp, 1983.

RESEARCH SUMMARY

Fission Track Studies A fission track laboratory has been set up and is in operation at Southern Methodist University. Several hundred dates have been obtained on apatite and zircon grains (and a few sphenes) from various geologic settings. As part of a separately funded but associated study, extensive annealing measurements have been carried out on apatite in order to better understand the systematics of annealing in geologic situations (Kelley, 1984; Kelley and Duncan, 1985b).

One of the initial objectives of the contract was to specifically apply some of the apatite results to the northwest United States, particularly the Cascade Range, however, rocks from the Cascade Range (in Oregon at least) have proved in general to have extremely small amounts of apatite and not be satisfactory for these kinds of studies. Separations were attempted for a deep hole near Mt. Hood and for surface samples in the Cascades. Samples were collected and apatites and zircons seperated from granites in a geothermal system in the Northern Cascade Range, i.e. the Meager Mountain geothermal system from southern British Columbia. Zircons and apatites were studied from this geothermal system in order to evaluate the thermal history. These results were discussed by Kelley and Blackwell (1984; see Appendix B). In addition, a few samples were studied from the geothermal system in Lakeview, Oregon in the Basin and Range province of south central Oregon. The results of this study are being prepared for publication.

Because of the lack of apatites in volcanic rocks in the Cascade Range, major emphasis was directed towards the tectonic history of the Rio Grande Rift, a major regional geothermal feature in New Mexico and the evolution of Basin and Range structure, specifically the Ruby Mountains of central Nevada. Both of these areas are active rift zones and represent dynamic areas of crustal deformation, volcanism, and fluid circulation. Apatite and zircon results have been used to constrain the thermal and uplift history of the Rio Grande rift (Kelley and Duncan, 1984, 1985a, Appendix C). Apatite and zircon studies have been very useful in illuminating the recent tectonic history of the Ruby Mountain structural block of the Basin and Range province in Nevada, Blackwell et al. (1984, 1985).

A final application of the fission track annealing results was to sedimentary rocks. Samples were obtained from wells in the Piceance Basin in Colorado. Three holes have been drilled there (MWX-1,2,3) under DOE contract to Sandia National Laboratories in order to study tight gas sands in the Mesa Verde formation. These holes have served as test sites for the evaluation and development of many different types of techniques and therefore represent an excellent place to study the apatite annealing technique.

Apatite fission-track ages were determined for 14 core samples of Mesaverde sandstone from the MWX-1 drill hole and for 3 core samples from the MWX-2 drill hole. Zircon fission-track dates were obtained for 3 cores from MWX-1 and for 1 core from MWX-2. In addition the fission-track length distributions in apatite samples were measured utilizing the methods of Lal et al. (1968). The track length measurement bias was removed using the relations outlines by Laslett et al. (1982).

The apatite fission-track ages are plotted as a function of depth in Figure 1. A regression line through all the data except the 24.3 Ma age at 4306 ft (1312.5 m) yields an apparent cooling rate of 177 m/Ma. These ages seem to record the cooling of the Mesaverde section during the erosion of the Colorado River, beginning approximately 9 Ma ago. The apparent cooling rate derived from the fission-track ages is comparable to the erosion rate of 167 m/Ma determined from the amount of erosion that has occurred since the

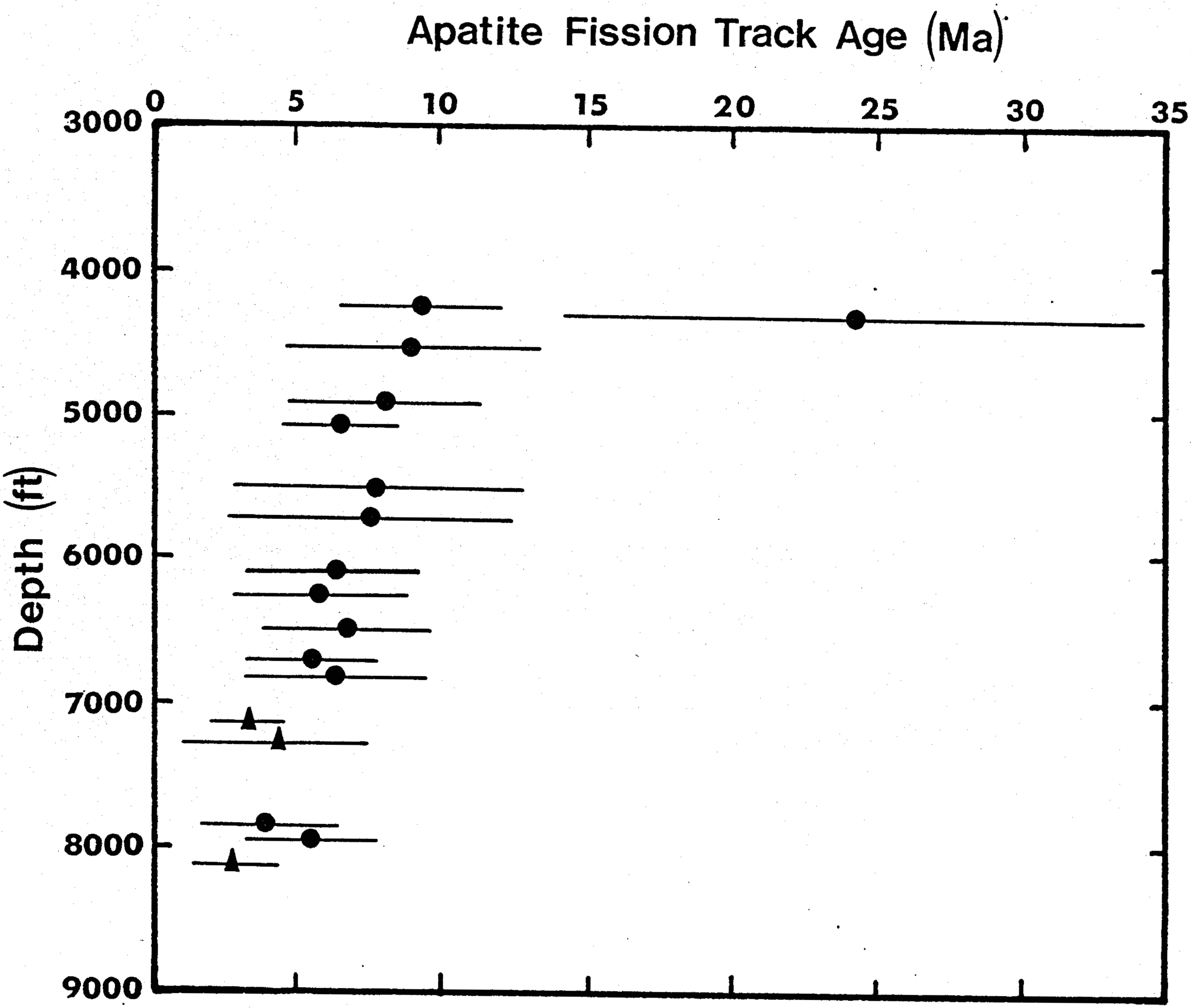

Figure 1. Plot of apatite fission-track age versus depth. The circles represent samples from MWX-1, and the triangles are samples from MWX-2. The arror bars represent two standard deviations.

emplacement of the 9 Ma old basalt flow that caps the on either side of the Colorado River valley near the drill holes (Bostic, 1983).

The track length distributions measured in 4 of the apatite samples from the MWX drill holes are shown in Figure 2. The 4306 ft (1312.5 m) sample has a bimodal distribution, which is characteristic of a sample that has been partially reset by a heating event that took place after the apatite was deposited in the sandstones of the Mesaverde Formation. The remaining samples have unimodal distributions, which are indicative of a slow cooling history (Gleadow et al., 1983).

The zircon fission-track ages from the MWX drill holes range in age from 77.0 to 132.7 Ma, and show no systematic trend with depth. These ages are average ages for each sample; the zircons are from different source areas, which leads to widely scattered ages. The zircon ages reflect the cooling ages of the source areas, and have apparently not been affected by heating subsequent to their deposition in the Mesaverde Formation.

The apatite fission-track ages from the MWX drill holes record the cooling of the Mesaverde section during the downcutting of the Colorado River. Approximately 9 Ma ago, the sampled section was buried under an additional 1500 m of sediments, and was at temperatures that were high enough to completely reset the fission tracks in apatite (around 130-150 C; see Hammerschmidt et al., 1984). The section at about 1300 m (present-day depth) was slightly cooler, because at about 1300 m (present-day depth) was slightly cooler, because the 4306 ft (1312.5 m) sample was not completely reset during burial, but was in the zone of partial stability for apatite. The sampled interval was never at temperatures of 200±25 C for a long enough period of time to affect the zircon fission-track ages. These observations are consistant with the results from the vitrinite reflectance study (Bostick, 1983).

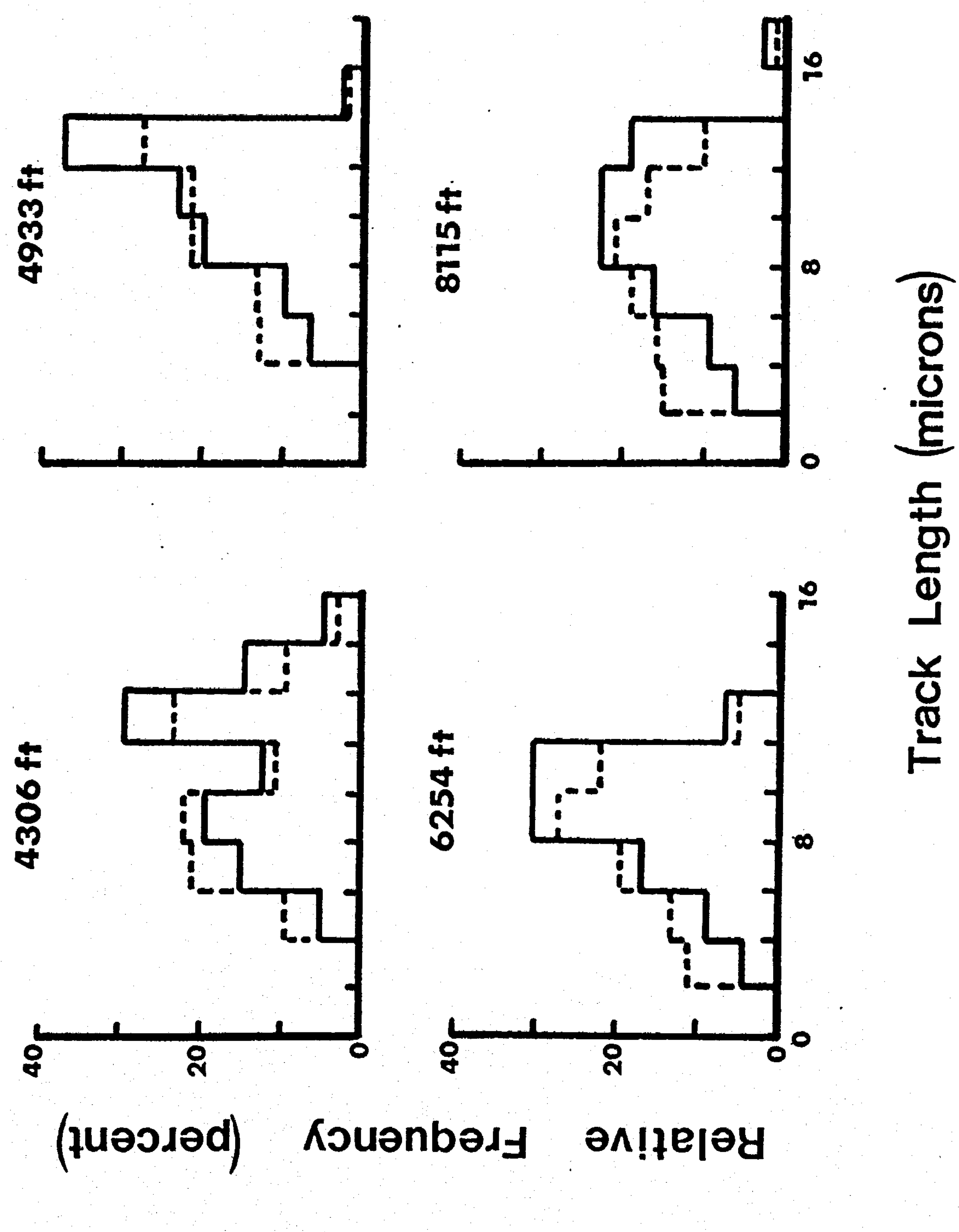

Figure 2. Fission track length distributions for apatite from core samples at 4306 ft (1312.5 m), 4933 ft (1503.6 m) 6251 ft (1905.3 m), and 8115 ft (2473.5 m). The solid lines represent the actual measurements; the dashed lines represent the theoretical histograms corrected for track length bias.

Fluid Flow in Geothermal Systems A final part of this contract was to study fluid flow in geothermal systems. Initially it was planned to combine the apatite dating with the fluid flow models to better constrain the temporal behavior of geothermal systems. This objective was accomplished. However, from matching temperature-depth curves, it appears that the ages of fluid flow indicated by overturned temperature-depth curves are on a different timescale than the apatite dating gives. This result is useful because the combination of the two approaches allows insights into different timescales of behavior in geothermal systems. Generally overturned temperature-depth curves give ages on the order of tens of thousands of years, whereas the apatite results are more useful for dating changes on a scale of hundreds of thousands to millions of years.

One of the surprising results from the application of the flow model developed by Ziagos and Blackwell (1985) to two geothermal systems is the rapidity with which thermal conditions change. An outstanding case is the Long Valley caldera in California. The results are documented in the appended paper. Consideration of the flow model indicates profound changes in the flow system in the long Valley caldera over the past few hundred years, perhaps in conjunction with emplacement of intrusive rocks and extrusive rocks along the western margin of the caldera associated with the Inyo Domes/Mono Craters chain of volcanism. Transient overflow conditions have also been noted for the Valles caldera (Harrison et al., 1985). These results represent important demonstrations of the timescale of temperature changes in geothermal systems are powerful tools to use in the exploration of such systems.

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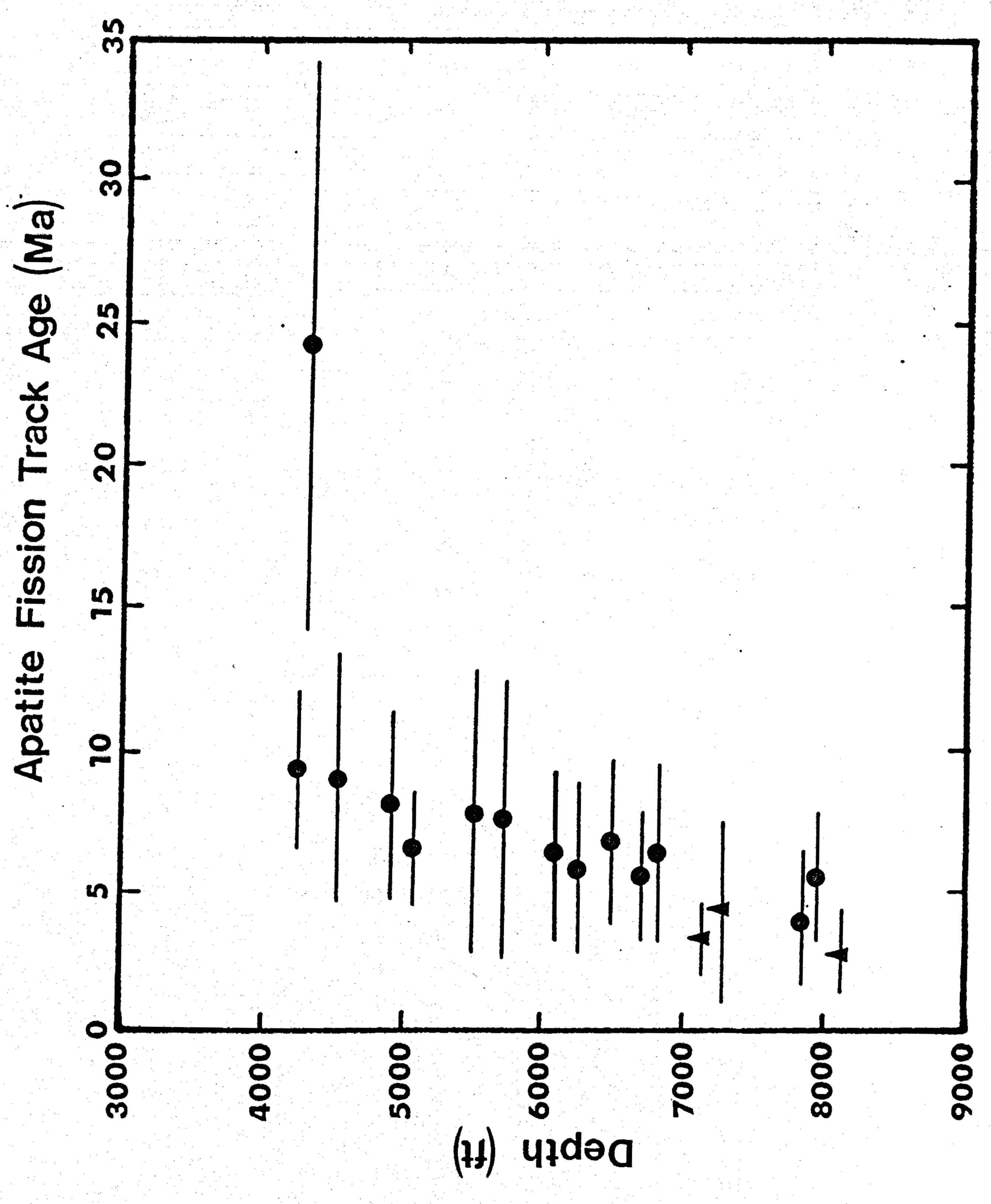

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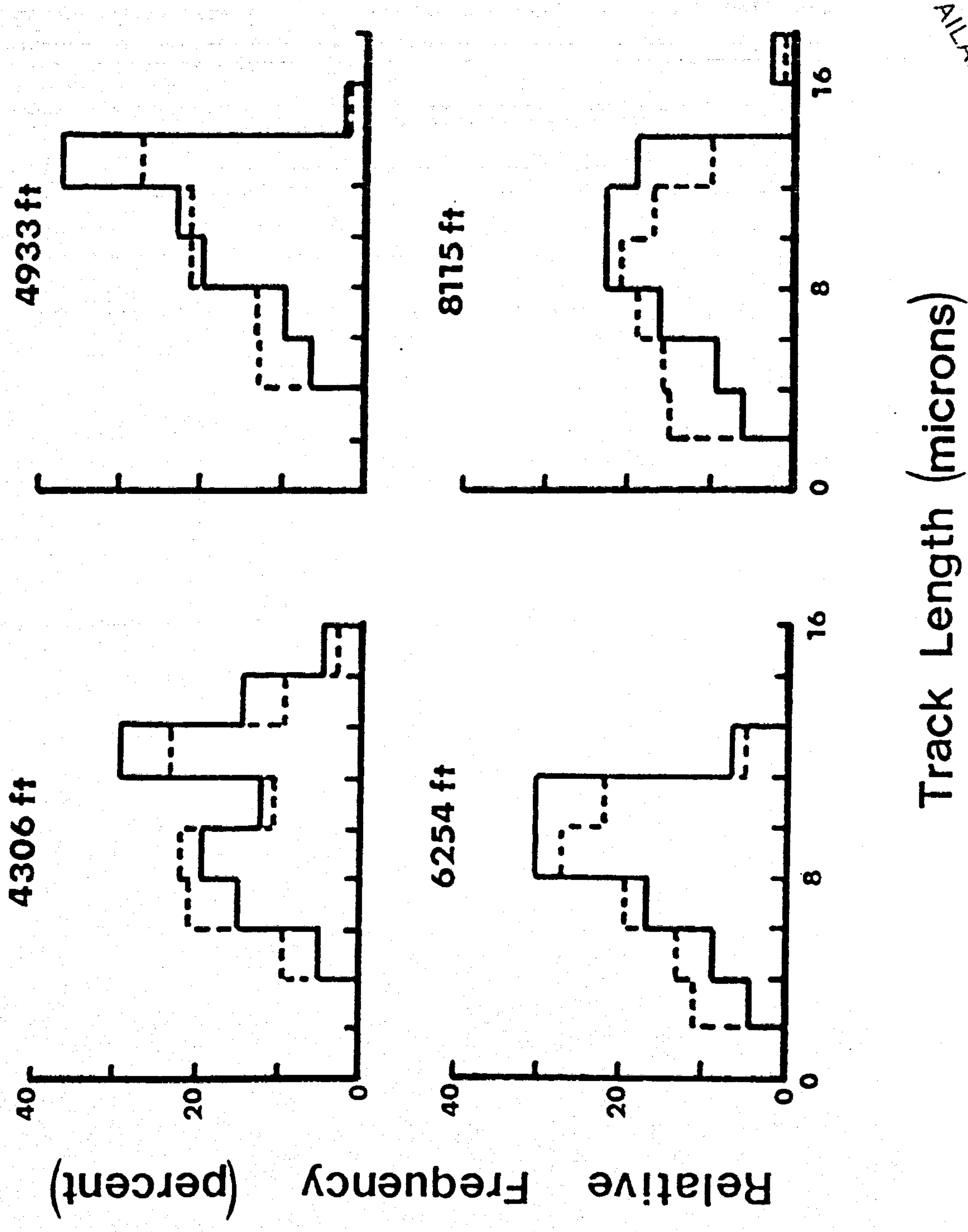

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