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Strontium isotopic aspects of *Paranthropus robustus* teeth; implications for habitat, residence, and growth

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ABSTRACT

The strontium isotopic ratio ^{87}Sr/^{86}Sr has been studied in the Sterkfontein Valley of South Africa to infer both habitat usage and residence for a number of early hominins. This paper examines the existing ^{87}Sr/^{86}Sr data collectively derived from three studies of *Paranthropus robustus* teeth with the aim of exploring whether the dataset as a whole may provide deeper insight into habitat, mobility, and growth for this species. ^{87}Sr/^{86}Sr from seven Swartkrans Member I third molars varies in a well defined narrow range, and while some canines were consistent with this range, a number of *P. robustus* canines and first and second molars were not, and therefore represent individuals who had arrived from other localities. A first and third molar ^{87}Sr/^{86}Sr was found to differ in TM1517c, the holotype *P. robustus* specimen from Kromdraai, suggesting this individual had moved to the locality sometime after the first molar and before the third molar had completely mineralized. While early forming teeth vary widely, the relatively low variation and absence of exogenous ^{87}Sr/^{86}Sr in third molars suggest that these teeth mineralized relatively late when compared to life history events bearing on higher primate residence patterns. The implications for further study of habitat, residence, and growth are discussed.

1. Introduction

Geographical variation in the ^{87}Sr/^{86}Sr of the Sterkfontein Valley presents unique opportunities for the study of early hominin behavior and biology. While the strontium ratio varies with the rubidium content and age of mineral substrates, it is not significantly fractionated by biological organisms (Graustein and Armstrong, 1983; Graustein, 1989; Kawasaki et al., 2002). Therefore, the ^{87}Sr/^{86}Sr of plants represents the available ^{87}Sr/^{86}Sr from substrates on which they grow. ^{87}Sr/^{86}Sr of animal calcified tissues reflects the circulating ^{87}Sr/^{86}Sr, which are derived from dietary strontium. To the extent that individuals moved across differing geological substrates or localities—having different ^{87}Sr/^{86}Sr—during growth and development, the different ^{87}Sr/^{86}Sr in those habitats will be reflected in ^{87}Sr/^{86}Sr variation in mineralized tissues, such as enamel, that were calcifying at various periods of growth.

^{87}Sr/^{86}Sr has been used in such diverse applications as source-tracing elephant ivory to specific African game reserves (van der Merwe et al., 1990), identifying the rearing streams of juvenile Atlantic salmon (Kennedy et al., 1997) and the preferred feeding habits of contemporary fauna of the Cape Fynbos region of South Africa (Radloff et al., 2010). The background to and growing applications of ^{87}Sr/^{86}Sr to source-tracing in ecological research have been extensively reviewed elsewhere (Bentley, 2006; Crowley et al., 2015).

Beginning with the work of Jonathan Ericson (1985), anthropologists have steadily expanded the use of ^{87}Sr/^{86}Sr to study paleontological, prehistoric, and historic human remains, and this has been reviewed extensively elsewhere (Bentley, 2006; Slovak and Paytan, 2011). The work has gone beyond comparison of different individuals to attempts to elucidate life-histories of individuals, both by sampling different teeth from the same skeleton (as in the case of the Alpine Iceman; Muller et al., 2003) and by examination of incremental structures within enamel (Dolphin et al., 2003; Kang et al., 2004; Richards et al., 2007).

^{87}Sr/^{86}Sr of habitat, fauna, and hominins of the Sterkfontein Valley have so far been explored in at least four studies (Hall, 1994;

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Sillen et al., 1998; Copeland et al., 2011; Balter et al., 2012), which viewed together answer certain questions, pose new questions, and leave many questions unanswered regarding hominin habitat, mobility, and growth. In this article, we will (i) briefly review the data reported so far, (ii) clarify the state of our knowledge in the light of subsequent critique, (iii) identify new, previously undescribed patterns in the existing published data, and finally, (iv) outline some questions yet to be answered and that are likely to be answerable with further study. Although data have been reported for numerous hominin species (and other biological markers such as carbon isotopes and Sr/Ca), this paper focuses exclusively on $^{87}Sr/^{86}Sr$ data pertaining to *Paranthropus robustus*.

2. Background

Hominin-bearing sites such as Swartkrans, Kromdraai, and Sterkfontein are located on a narrow dolomite band that is part of the Malmani Subgroup, Chuniespoort Group of the Proterozoic Transvaal Sequence. To the northwest of the site, rocks of the Pretoria Group of the Transvaal Sequence consist predominantly of quartzite and shale, with a prominent volcanic unit, the Hekpoort Andesite Formation. Further to the northwest is the Daspoort Quartzite Formation, then alternating bands of diabase and undifferentiated surface deposits. To the southeast of the site, the dolomite gives way to rocks of the Witwatersrand Supergroup, which are underlain by Archaean Granite dated approximately 3 Ga (Geological Survey, SA, 1989). This granite is exposed to the east of Swartkrans. Remaining areas of the Witwatersrand Supergroup are represented by the Krugersdorp Quartzite Formation, with occurrence of quartzites, shales, and conglomerates (Fig. 1).

Examination of $^{87}Sr/^{86}Sr$ patterns in the region showed very high variation in whole soil $^{87}Sr/^{86}Sr$ derived from these substrates, but somewhat less variation in available soil and plant $^{87}Sr/^{86}Sr$ (Hall, 1994; Sillen et al., 1998). In this system, highly radiogenic strontium from the ancient rocks and insoluble components of the dolomite mix with the relatively depleted strontium from soluble components of the dolomite. Given that this ratio is routinely measured to the 5th decimal place, the $^{87}Sr/^{86}Sr$ endmembers for this system are extraordinary for their wide divergence: 0.90060 for the Archaean granite at the high end and 0.70861 for the soluble components of the Malmani Formation dolomite at the low end. Because of mixing and heavy domination by the dolomitic soluble strontium, habitat and biome variation in Sterkfontein Valley $^{87}Sr/^{86}Sr$ generally lies between 0.72000 and 0.75000.

Since streams and their adjacent greenbelts are heavily dominated by the less radiogenic (soluble) strontium, wet streamside habitats have more depleted $^{87}Sr/^{86}Sr$ than upland, drier habitats (Sillen et al., 1998). This phenomenon similarly existed in the Pleistocene, as demonstrated by $^{87}Sr/^{86}Sr$ of carbonate from the Swartkrans Cave; Member I breccia was found to have $^{87}Sr/^{86}Sr = 0.7217 \pm 0.0009$, well within the range of modern Blaaubank stream water and nearly indistinguishable from modern water obtained at Swartkrans. Further study of the Sterkfontein Valley system confirmed relatively radiogenic $^{87}Sr/^{86}Sr$ in habitats

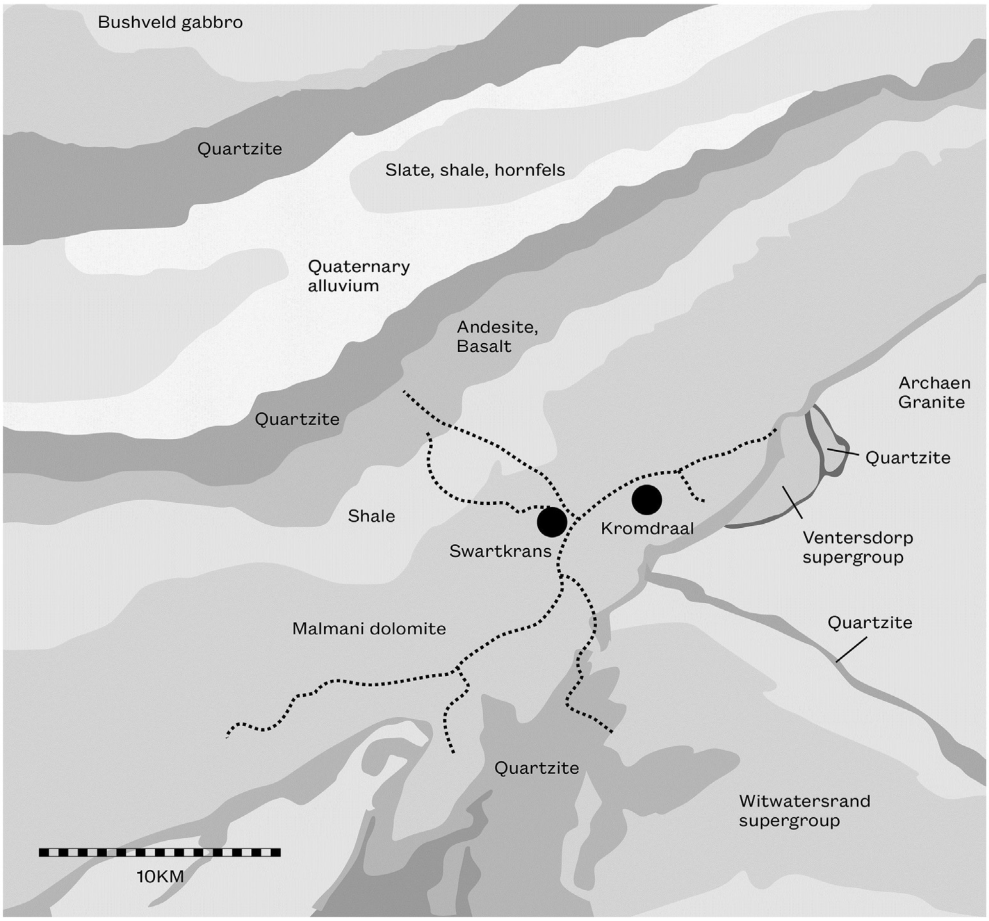

Figure 1. Sterkfontein Valley geology, showing the locations of Swartkrans and Kromdraai on the Malmani dolomite, and the course of the Blaaubank stream in the immediate vicinity of the sites.