ratio for undepleted mantle inferred from the Os isotopic evidence fulfills a prediction of the late influx model (LIM) which is not inherent in the inefficient core formation model (ICFM). Second, if the LIM is accepted as a working hypothesis, the mantle Os/Re ratio, closely constrained by the Os isotope measurements, allows tentative inferences concerning the composition of the late influx.

The ICFM requires chondritic ratios of highly siderophile elements (HSE) *a priori* only if <1% unfractionated chondritic metal and sulphide can be retained in the mantle after core formation. However, marked fractionation between solid metal (SM) and 'liquid metal' (LM; actually a metal-sulphide eutectic) is an important feature of the ICFM[2]. Thus, the partition coefficients between SM and LM [D(SM/LM)] are important to Os/Re fractionation. Only if the D(SM/LM)s for Os and Re are similar will a chondritic ratio be preserved. For Os, D(SM/LM) has not been measured experimentally. Data for metal and troilite (FeS) in the Odessa IA iron meteorite[3] suggest a value for Os that is >50 times that of Re, although troilite may not be an ideal analogue for LM[4].

Reference to magmatic iron meteorites (MIM) by Jones and Drake is misleading. The fractionation in MIM is between a low-Ni solid and a high-Ni liquid, with S playing only a minor role. Separation of any Fe–FeS eutectic (analogous to SM) would have taken place before the fractionation preserved in MIM[5].

The variation of the Os/Re ratio in chondrites has been known for almost 20 years[6], and one purpose of ref. 1 was to re-state this with modern data. Because the LIM is rigid in postulating the preservation of chondritic proportions, it allows the implications of the mantle Os/Re ratio to be explored in terms of the fine structure of chondritic composition.

To summarize, the LIM firmly predicts chondritic HSE ratios, and is supported by the isotopically derived mantle Os/Re ratio, so that its further implications may reasonably be explored. The ICFM may be able to accommodate the observed Os/Re ratio, but because many important inputs are currently unknown, its predictive value is weak.

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Age interpolation

THE equivalence of depth to age in a stratigraphic sequence can normally be established (radiometrically or palaeontologically) at only a finite number of discrete points. Age estimation between such points is impossible because sedimentary accumulation is the result of sedimentation minus erosion. The sedimentation rate (measured over short periods of time) generally far exceeds the accumulation rate (measured over long periods[1]), producing a record composed of packets of rather rapidly deposited sediment separated by hiatae (unconformities) of variable duration. Without physically based assumptions, any interpolation is generally inaccurate; moreover, an estimate of standard error at one level of a sequence will not generally apply to another.

Attempts have been made to produce depth to age conversions using a variety of assumptions (such as linear changes in deposition rate or constant rate), with the conversion produced depending critically on the assumptions[2–5].

The absence of suitable radiometric markers in ancient sediments guarantees that this problem will always limit the interpretability of the geological record, yet attempts persist to surmount this geological uncertainty by using not physically based reasoning, but statistics involving 're-sampling' at a scale finer than that originally present.

Badgley *et al.*[6] have proposed another variation on the theme, arguing that it is permissible to re-sample to a finer time scale than that of the original dated horizons. Indeed they "use the pattern of sediment accumulation for a younger portion of the sediment regime to estimate the variance in an older part of the regime; the implied assumption of stationarity is justified by the linear pattern of cumulative stratigraphic thickness over the entire Kaulial sequence". Perhaps it is, but that is essentially the point that one wishes to prove and not assume, or else a circular argument is produced.

Such 're-sampling' techniques are capricious because (1) the functional type of the re-sampling filter is chosen arbitrarily; (2) the 're-sampled' data contain noise not only from the original data but also from variations in the subjectively selected parameters of the re-sampling filter of given functional type; and (3) linear interpolations are not more, or less, accurate than any other interpolation, irrespective of the time gap between dated horizons[2,7].

And yet we find the claim[6]: "The standard error calculated by this resampling method can be considered a minimum value attributable to variability in sediment accumulation rate". Perhaps, but until knowledge of the true depth to time conversion is available, it is simply not possible to say whether the statistical error is a minimum or not, all protestations to the contrary notwithstanding. Also, it is not possible to say whether the estimated stratigraphic horizon ages are systematically in error due to the underlying assumptions made.

We are surprised, and dismayed, to see the idea promulgated that one can estimate age and variance from yet another purely arbitrary interpolation scheme as proposed[6]. Playing in the cracks between the piano keys produces a tune only for the deaf.

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BADGLEY *ET AL.* REPLY—Stratigraphers often find it useful to estimate the age of a datum that lies between levels of known age. In the absence of other information, no age estimate is better than the linear interpolant. Moreover, regardless of one's theory of how sediment accumulates, the best guide to the uncertainty of any such estimate is the actual error observed for comparable quantities in comparable conditions. The primary objections of Ehrlich and Lerche are that (1) age estimation between dated levels in a stratigraphic sequence is impossible and (2) an estimate of variance in sediment accumulation rate in one stratigraphic interval should not be applied to a neighbouring interval.

If a fossil found midway between two horizons of known age were assigned an age halfway between, it would be pointless to declare that the error of this estimate is half the interval in question. But Ehrlich and Lerche imply this upper limit as the estimate of such errors ("age estimation ... is impossible"). Our method reduces this unnecessarily wide uncertainty by considering errors observed for the same estimate from neighboring strata in which magnetic reversals are more closely spaced. For the "*Hipparion*" datum in Pakistan, we assumed that the magnitude of this error over intervals of ~1.5 Myr in the range 6.34–8.56 Myr would be a reasonable guide to the variability from 8.56 to 10.00 Myr. The linear relationship between sediment thickness and absolute time from 6.34 to 10.00 Myr supported this assumption, and nothing in the data contradicted it. We stand by our estimate of ±90,000 yr.

Ehrlich and Lerche are mistaken about three other points. (1) Our re-sampling involves no palaeomagnetic intervals of shorter duration than those originally measured. (2) No re-sampling 'filter' is involved. (3) Our statement that error due to all forms of uncertainty should not be systematic simply means that interpolated age estimates should be too high about as frequently as they are too low.

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Are enigmatic markings in Adelaidean of Flinders Ranges fossil ice-tracks?

SEVERAL questions may be raised concerning the provenance of markings recently described by Dyson[1] as "unequivocal metazoan remains" from the "base" of the "Wilpena Group" in the southern Flinders Ranges, South Australia. Dyson[2] indicated that the markings occurred in sandstones ~25 m stratigraphically below a dolomite bed representing the Nuccaleena Formation. This dolomite is the regional marker for the base of the Wilpena Group in the western Flinders Ranges[3]; it is discontinuous in the vicinity of the markings (near Wilmington) but locally reaches a thickness of ~7 m. Directly below it is 11-20 m of maroon-coloured, silty diamictite containing sub-angular to sub-rounded clasts up to 1 cm in diameter. Interlayered sandstones and siltstones at the indicated level of the markings are underlain by pink sandstones which also contain trains of exotic granules and pass laterally into sandy diamictites containing pebbles up to 3 cm. The sandstones variously show flat internal lamination and cross-bedding; stacked sets of ripple bedding outlined by heavy minerals are common and are related to linguoid current ripples and wave oscillation ripples. These diamictites and sandstones are diagnostic facies of the Elatina Formation[4], the glaciogenic interval of the Marinoan and upper division of the Umberatana Group.

Refrigeration during deposition of the Elatina Formation is attested by widespread varvites and common ice-rafted clasts. Pebbly arenites within the unit have been assigned a glaciofluvial or deltaic origin[5]. In a coeval terrestrial setting, laminated sandstone wedges formed in harsh periglacial conditions[5].

Dyson[1] suggested a similarity between the markings and known Precambrian frond-like fossils such as *Pteridinium* and *Charniodiscus*, but *Pteridinium* was evidently rather resilient or 'rubbery' and despite common folding and distortion, the transverse 'ribs' are generally quite regular in width, respectively 2-3 mm and 3-5 mm wide in several described forms. The transverse elements in *Charniodiscus* vary in width (~2-28 mm) with the size of the organism, but show a progressive gradation in dimensions along the frond. Parts of the markings show rapid changes in the width of the ribs, from 2 to 6 mm and from 1 to 10 mm wide in limited areas. Moreover, different numbers of ribs occur on either side of given intervals of the 'axis' of the 'bilateral' marking.

In size and in showing numerous nearly parallel longitudinal striae, the markings may be compared to a group of broadly intergrading inorganic sedimentary structures variously described as grooves and transverse shear wrinkles[6], or interrupted chevron marks and striae with 'jigger' marks[7]. Linear grooves result from current-transported objects touching bottom, and chevrons may develop due to hydrodynamic conditions generated if such objects move just above the substrate[7]. Transverse shear wrinkles have been formed experimentally by passing dense suspension currents over plastic substrates[6]. 'Jigger' marks associated with parallel grooves are evidently made by floating objects touching bottom, and examples are commonly attributed to floating ice[7]. Oscillatory motions imparted to the ice by waves may lead to sets of transverse marks showing cyclical changes in width[7]. The Marinoan markings show just such changes in the width of the 'ribs' (Fig. 1) and their proximity to ice-rafted materials lends circumstantial evidence to their formation by a similar process. Comparable

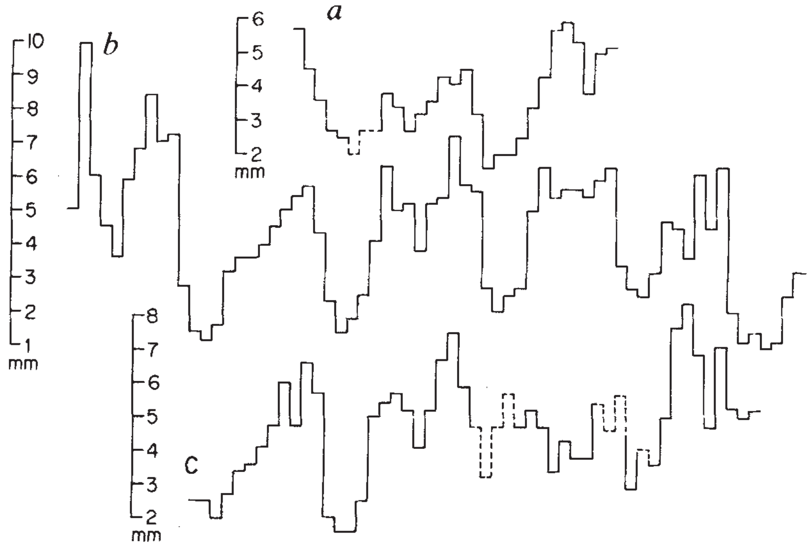

Fig. 1 Cyclical changes in width of ribs in structures described by Dyson[1] from the Flinders Ranges: *a*, series of ribs from left to right in marking 'a' in Dyson's Fig. 3; *b*, upper row of ribs in 'b'; *c*, lower row in 'b' shifted laterally (right) to show maximum correspondence with row above. The mean cyclicity indicated by groups of fine ribs is ~12 ribs and grooves.

markings formed by ice on the modern-day tidal flats of the St Lawrence, Quebec are illustrated by Dionne[9] (his Fig. 19).

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