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Possible evidence for Late Cretaceous off-axis volcanism in the outer James Ross Basin

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Abstract: A prominent volcaniclastic channel sandstone deposited by a landward-flowing sediment gravity flow is described from the Maastrichtian of Snow Hill Island in the northern Larsen Basin. The characteristics of this petrographically distinct event deposit appear to indicate a volcanic source to the east of Snow Hill Island, well away from the magmatic arc landmass which sourced the bulk of the Larsen Basin fill, suggesting minor off-axis intrabasinal volcanism in Maastrichtian to Paleogene times.

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Introduction

The Larsen Basin is a major Cretaceous–Tertiary sedimentary basin on the eastern (back-arc) margin of the Antarctic Peninsula magmatic arc (Fig. 1). Extensive exposures of the uplifted basin fill occur in the James Ross Island area, the northern sub-basin of the Larsen Basin, generally referred to as the James Ross Basin (del Valle *et al.* 1992). Here, a minimum stratigraphical thickness of 6 km has been measured (Fig. 1), making it one of the thickest (and most complete) onshore Cretaceous–Paleogene successions in the Southern Hemisphere (e.g. Pirrie *et al.* 1997). Regional considerations, together with sedimentological studies of the basin fill, have indicated a relatively simple pattern of sediment derivation from the adjacent arc. Sandstone petrography can be readily matched with the major geological units forming the northern Antarctic Peninsula (Pirrie 1991), and palaeocurrent data from various stratigraphical intervals support westerly to north-westerly derivation from the northern Antarctic Peninsula (Ineson 1985, 1989, Pirrie 1989, Lomas in press). However, not all data fit this simple picture. This paper discusses the possibility of additional volcanic sediment sources within the distal part of the basin, roughly 100 km east of the main axis of arc volcanism.

Field data from Snow Hill Island

Spath Peninsula on northern Snow Hill Island (Fig. 1) exposes a thick and continuous section through the Snow Hill Island Formation, the central portion of the Marambio Group, which is essentially Maastrichtian in age (Pirrie *et al.* 1997). The stratigraphy and sedimentology of the Spath Peninsula succession are discussed in detail by Lomas (in press). Most of the succession is composed of unlithified, heavily bioturbated fossiliferous muds and fine sands deposited in a range of shallow marine environments. Petrographic data are consistent with sediment derivation from the northern Antarctic Peninsula but the intense bioturbation means that palaeocurrent indicators are not commonly preserved. Only one stratigraphical interval, the lower part of the Haslum Crag Member of Pirrie *et al.* (1997), exposes beds in which levels of bioturbation are weak enough to reveal primary directional current structures.

Lower Haslum Crag Member

This is a relatively sand-rich package of variably bioturbated glauconitic sediments (Fig. 2) deposited in essentially 'outer shelf' environments during a period of rising relative sea-level (Lomas in press). Thick redeposited tuffaceous beds (ash turbidites), and slightly increased proportions of volcanic lithic grains testify to a phase of increased volcanic activity in the area. Much of the sand was probably introduced by storm-generated currents (Lomas in press). Where only weakly bioturbated, these sands preserve evidence of flow direction in the form of ripple cross-lamination. The foreset azimuths of these cross-sets indicate E- to ESE-directed palaeoflow (Fig. 3a), which is the expected dominant sediment dispersal direction, towards the depocentre and away from the emergent source terrain to the west. However, one very prominently exposed sandstone within the lower Haslum Crag Member shows palaeocurrent indices from the opposite direction (Fig. 3b). The bed occupies the base of a major channel structure (Fig. 4a) which truncates bedding in the underlying units at relatively high angles and has an overall down-cutting relief of approximately 32 m.

Channel-base sandstone

The channel feature has a poorly exposed, mud-dominated

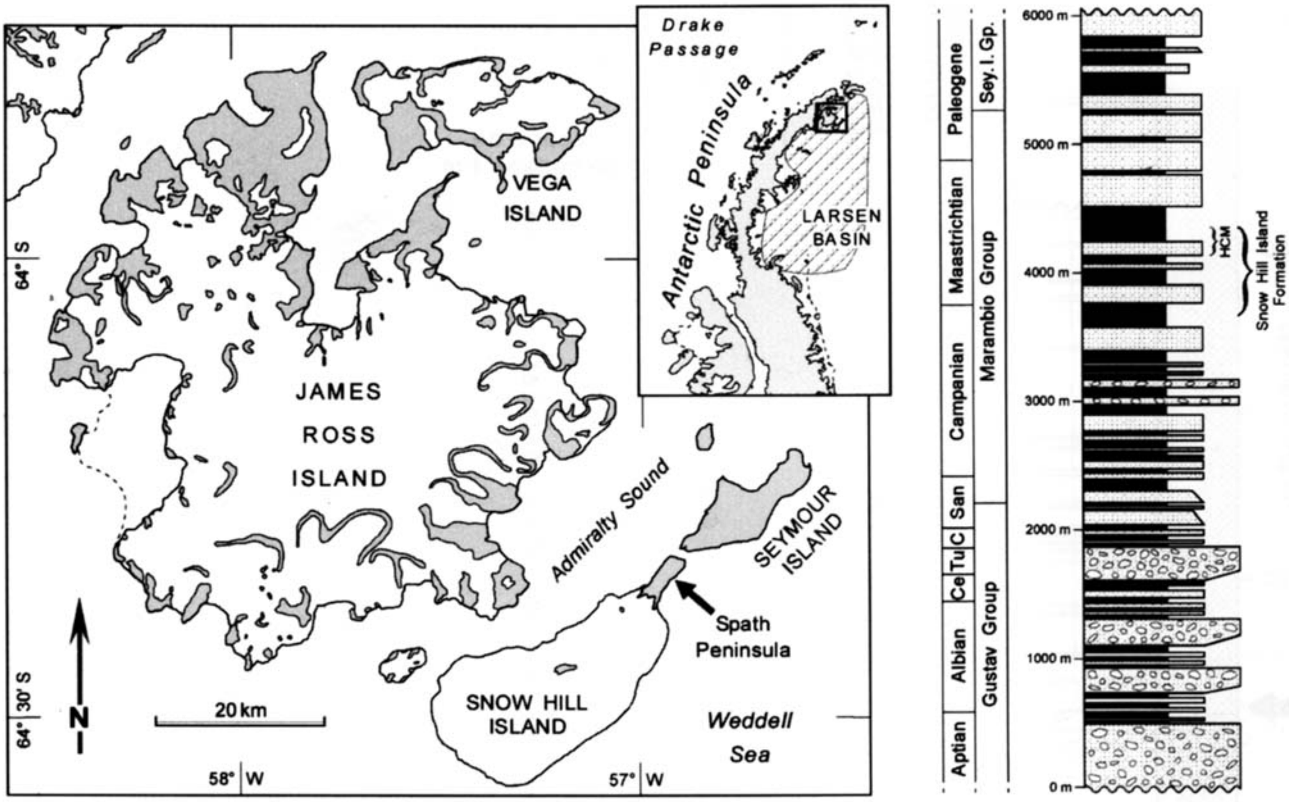

Fig. 1. Location map and simplified stratigraphy of the Larsen Basin fill exposed in the James Ross Island area. Stratigraphic column modified after Macdonald *et al.* (1988). Abbreviations: C = Coniacian, Ce = Cenomanian, HCM = Haslum Crag Member, Tu = Turonian, San = Santonian, Sey. I. Gp. = Seymour Island Group.

fill, but the channel base itself is veneered by a conspicuous sharp-based graded sandstone bed (Fig. 4). The bed is only 8–15 cm thick on the channel flanks, but thickens dramatically towards the channel axis, where a maximum thickness of 268 cm is attained. There the bed comprises a "Bouma-type" sequence of well-defined, structureless, plane-laminated, and cross-laminated divisions. Rare basal flute marks indicate WNW-directed flow. Away from the channel axis, the basal coarse structureless division is absent (Fig. 4b). Plane-laminated divisions are associated with strong WNW–ESE-trending parting lineations (Fig. 3c). Overlying cross-laminated divisions show essentially unimodal (NW–WNW-directed) ripple foresets (Fig. 3b), locally with preserved stoss-side laminae (climbing ripples).

Compositionally, the channel-base sandstone is quite distinct from other sandstones from this part of the succession (Fig. 5). It is very rich in both glaucony and volcanic lithic (Lv) grains (together making up 45–70% of the framework composition), including degraded volcanic glass. The presence of clear glaucony, glaucony with relict igneous textures, and partly altered lithics implies glaucony formation by diagenetic replacement of precursor Lv grains. The variable degrees of alteration suggest that much of the Lv fraction may be reworked older material rather than of neovolcanic origin. The extensive alteration also precludes useful chemical analysis of the volcanic debris. Virtually all the lithic grains in this bed (and in the Snow Hill Island Formation in general) are of volcanic origin (chiefly andesitic in composition), although a few metasedimentary fragments are present (<2%). Non-lithic grains are dominated by monocrystalline quartz (10–21%), plagioclase (6–18%), K-feldspar (3–12%), plus minor biotite, polycrystalline quartz, hornblende and opaques (total accessories < 2%). A carbonate cement accounts for up to 10% rock volume. Modal composition varies systematically with grain-size through the graded bed such that the coarser (medium to medium/coarse sand grade) fraction of the bed is particularly rich in volcanic lithic fragments whereas other siliciclastic components make up a subequal proportion of the fine sand fraction (Fig. 5).

Although the channel-base sandstone is petrographically distinct from the rest of the Snow Hill Island Formation on Spath Peninsula, Pirrie (1994) has described similar modal compositions for two thin graded sandstones from the Cape Lamb Member (also Maastrichtian) on Vega Island (see Fig. 1). Palaeocurrent data are not reported but is interesting to note that the upper of these beds lies within the lithostratigraphical interval which is now thought to correlate with the lower Haslum Crag Member on Spath Peninsula.

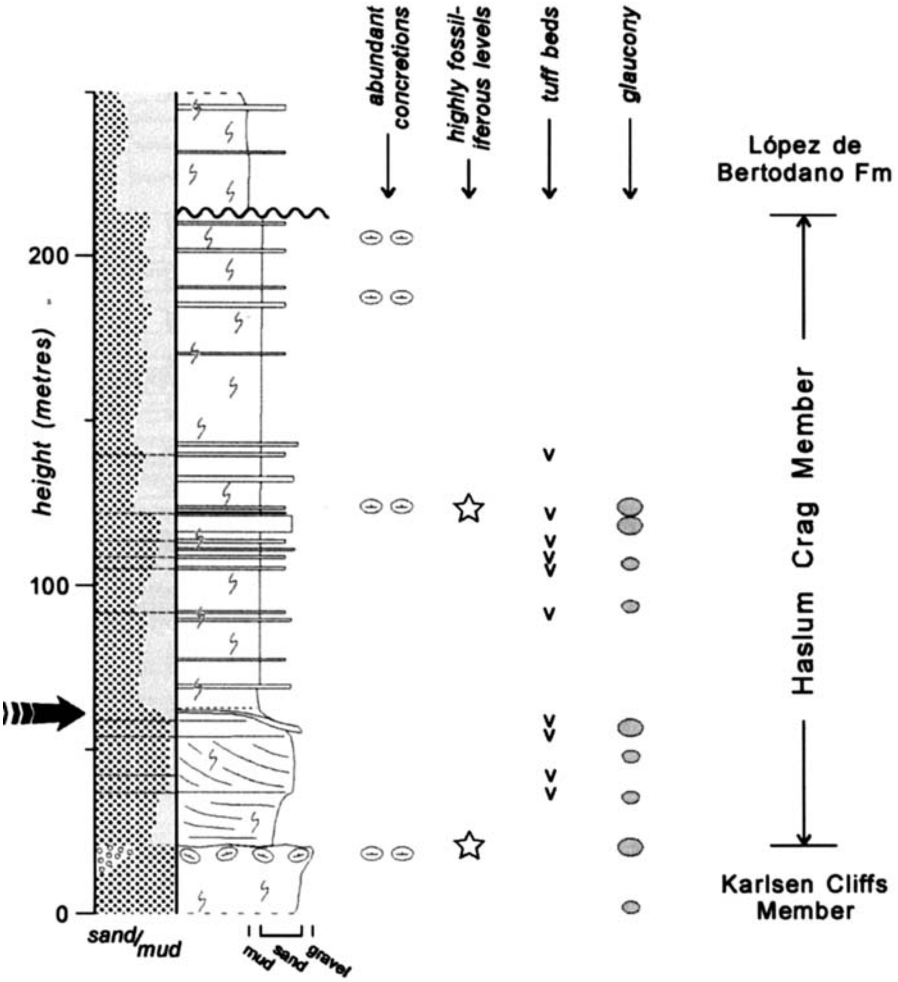

Fig. 2. Sedimentary log through the Haslum Crag Member. Large arrow indicates position of channel sandstone.

Depositional model

The channel-base sandstone was clearly deposited by a confined sediment gravity flow and could be termed a classical turbidite. Palaeoflow towards the NW or WNW is indicated both by flute marks at the base of the bed (produced by erosion beneath the head of the flow) and by ripple lamination at the top of the bed (produced during late-stage traction). Hence

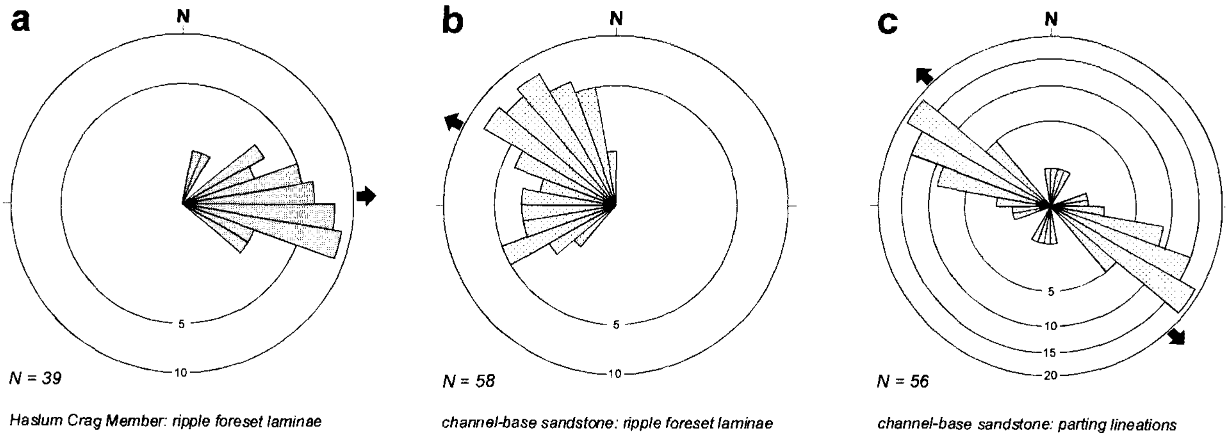

Fig. 3. Rose diagrams of palaeocurrent indicators from the lower Haslum Crag Member, arrows show vector mean azimuths. **a.** Data from the main part of the member, indicating palaeoflow towards the east or ESE. **b.** Orientation of ripple foreset laminae from upper part of channel-base sandstone, showing WNW-directed palaeoflow. **c.** Parting lineation trends from plane laminated division of channel-base sandstone, showing WNW–NW axis of flow.

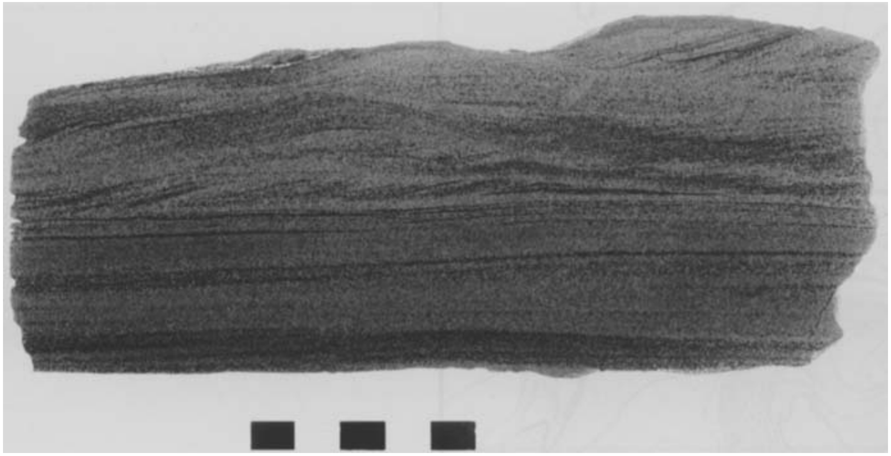

Fig. 4. a. View looking south-east at the southern margin of the channel structure discussed in the text, showing thickness change of channel-base sandstone and trace of bedding above and below. Rucksack (circled) is 80 cm high and height of visible section is *c.* 15 m.
b. Polished slab of the channel-base sandstone from the channel margin, showing the lower plane-laminated division and the upper ripple-drift cross-laminated division. Palaeoflow to the left. Scale bar divisions are in centimetres.

flow appears to have been unidirectional throughout its duration, and flow reflection (cf. Kneller *et al.* 1991) does not appear to be responsible for the landward-directed palaeocurrent indicators. In view of the high content of primary volcanic debris, an eruption-triggered sediment gravity flow event seems possible. Thus we can envisage flow initiation by a volcanic event, leading to mixing of pyroclastic material with remobilized unconsolidated sediment entrained by a current which was initially highly energetic and erosive. Although it is unlikely that channel-cutting and deposition of the channel-base sediment were accomplished by the same current, some genetic relationship seems likely. Channel excavation may have occurred almost instantaneously as a slope collapse event, or over a period of time through repeated scouring beneath bypassing gravity currents. Exposure of the channel margins is too poor to discriminate, but in either case, the formation of a deep WNW-sloping channel requires a local sea-floor inclination up to the ESE.

Discussion

A volcanic source to the ESE seems to be the best explanation for this WNW-flowing event deposit. However, as palaeocurrent indicators above and below this channel are

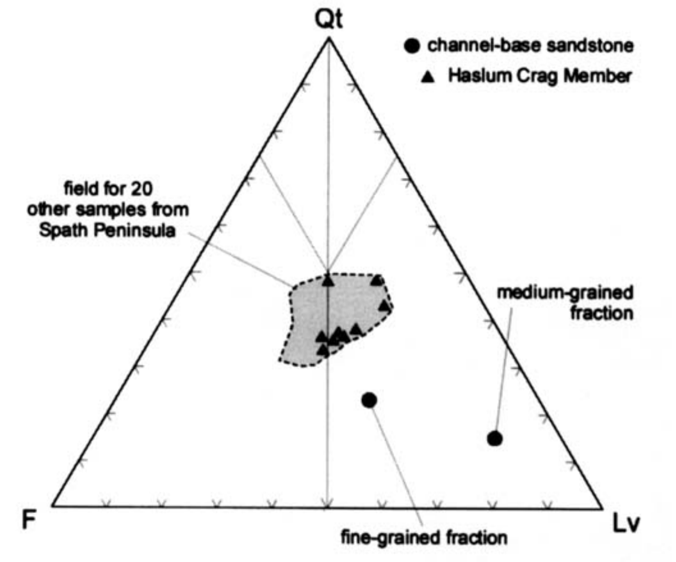

Fig. 5. Sandstone composition plotted in QtFLv space, highlighting the anomalously lithic-rich composition of the channel-base sandstone relative to the rest of the succession on Spath Peninsula. Qt = total quartz grains, F = total feldspar grains, Lv = volcanic lithic grains.

ESE-directed, we can presume that the WNW-directed palaeoflow represents an anomalous event rather than a major upheaval in basin geometry and sediment dispersal patterns. Although the lithic-rich turbidite described is only a single unit within a thick stratigraphical succession, it is significant relative to the sparse dataset of palaeocurrent azimuths available from the Marambio Group as a whole.

Volcanism in the Antarctic Peninsula region peaked during the Early Cretaceous, waning markedly into the Late Cretaceous (Leat *et al.* 1995). However, Campanian–Maastrichtian axial calc–alkaline mafic volcanic rocks are known from some small islands near the north-east tip of the Antarctic Peninsula (Baker *et al.* 1977, Hamer & Hyden 1984), immediately north of the James Ross Basin. Intrabasinal volcanic centres of pre-Miocene age have not previously been recognised within the Larsen Basin, but Elliot (1997) has recently raised the possibility of a Paleogene volcanic source area east of Seymour Island to account for field relations in the Cross Valley Formation on that island. It is uncertain whether a Maastrichtian or Paleogene volcanic centre would be recognisable as a bathymetric feature today, but this must be viewed as a possibility given the comparative weakness of the mud-rich, poorly consolidated sediments of the James Ross Basin. At present, the age and composition of the sea-floor in this area

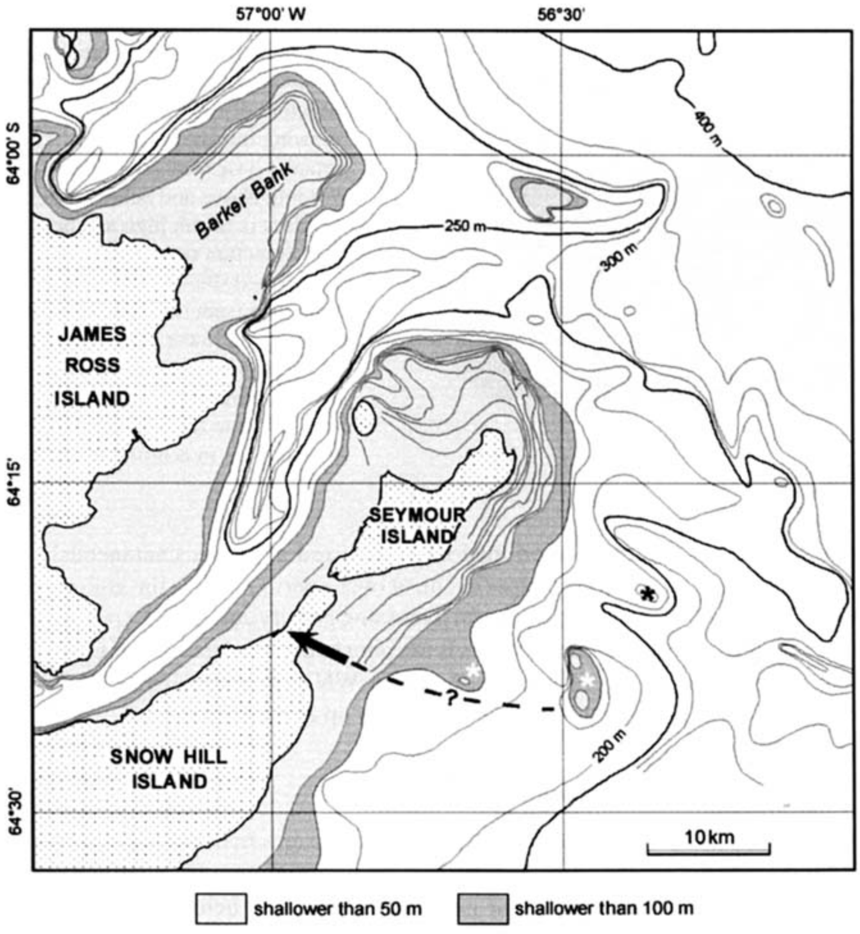

Fig. 6. Cartoon of the present day bathymetry of the outer James Ross Basin area, based on data from 1994 British Admiralty chart. Arrow on northern Snow Hill Island indicates mean palaeocurrent direction of channel-base turbidite discussed in the text (exposure is at arrow tip). Asterisks indicate possible sources.

is poorly known. Only very limited geophysical data are available from the surrounding continental shelf (cf. Anderson *et al.* 1992, Sloan *et al.* 1995), but bathymetric data do show a small number of pronounced positive sea-floor features (Fig. 6). In particular, one conspicuous bathymetric high some 20 km ESE of Spath Peninsula appears to be an ideal candidate for the source of the volcanic turbidite described above. In the absence of geophysical data or direct observation, this remains highly speculative, but the hypothesis could be readily tested by seismic or aeromagnetic studies of the region.

Conclusions

It is clear that the bulk of the fill of the Larsen Basin was derived from the adjacent Antarctic Peninsula magmatic arc. However, the prominent landward-flowing sediment gravity flow described here appears to require a volcanic source to the east of Snow Hill Island, well away from the main arc landmass. This, together with compatible inferences from Seymour Island (Elliot 1997), provides evidence for minor off-axis intrabasinal volcanism in Maastrichtian to Paleogene times. Bathymetric data from the area suggest a number of candidate palaeovolcanic centres, and we would encourage future geophysical surveys to target these features.

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