GOLD DISPERSION IN CALCRETE-BEARING REGOLITH OF THE GIRILAMBONE REGION, WESTERN NSW

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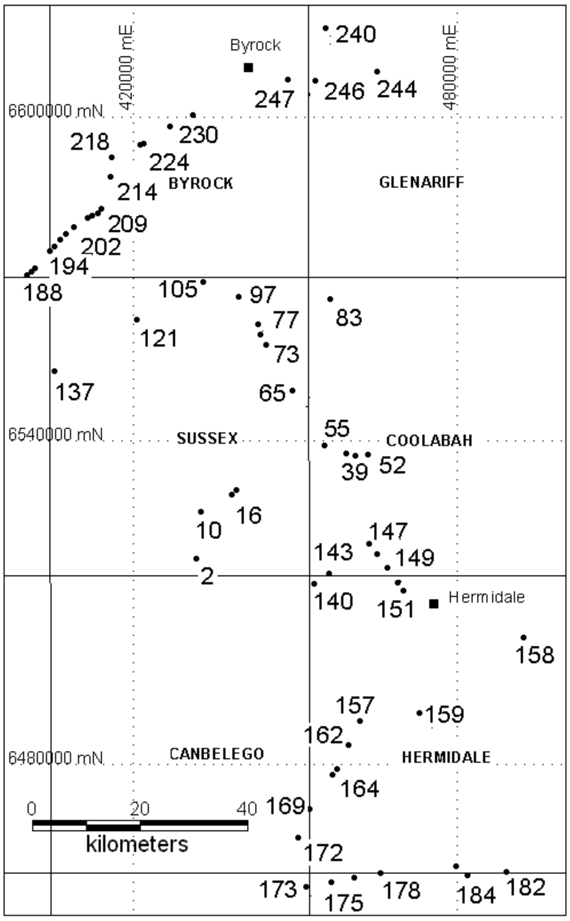
INTRODUCTION

Regolith carbonate (or calcrete) is widely distributed in the semi-arid regions of southern Australia and has been used as a sampling medium in geochemical exploration for gold and some base metals (e.g. Lintern & Butt 1998; Hill *et al.* 1999; McQueen *et al.* 1999; Chen *et al.* 2002). Calcrete forms by cementation and displacive and replacive precipitation of predominantly calcium-rich carbonate into soil profiles, transported and *in situ* regolith, and bedrock, in areas where pore water and groundwater become saturated with respect to calcium carbonate (e.g. Durand *et al.* 2006). This article examines the geochemical characteristics of calcrete-rich zones intersected during a regional roadside drilling program in the Girilambone region of western New South Wales (Figure 1).



Drill holes

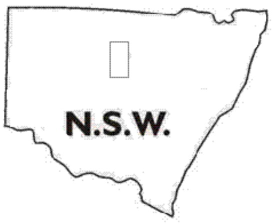


Figure 1: Location of the Girilambone region in western New South Wales and detailed plan showing location of drill holes with observed calcrete.

NATURE AND REGIONAL DISTRIBUTION OF REGOLITH CARBONATE

Regolith samples were collected at 1 m intervals in the top 10 m of air-core drill, holes and at 3 or 6 m intervals below this. Calcrete zones were identified by visual logging, testing with hydrochloric acid, X-ray diffraction analysis of samples (from a limited number of sites) and assessment of the major element content following chemical analysis. It was difficult to recognise the morphological characteristics of most of the calcrete in the pulverised composite samples, but observations of exposed calcrete throughout the region indicate at least four calcrete facies in regolith with elevated values of Ca (≥1.0 wt%) and/or Mg (≥1.0 wt%). These facies are: i) coated grains and nodular carbonate; ii) powdery carbonates; iii) massive or laminated carbonate hardpans; and iv) vein-filling carbonate (see also McQueen 2006). The first two are weakly consolidated and generally associated with carbonate hardpans, which are common within soil and alluvial/colluvial sediments. The third facies occurs in regolith profiles where carbonate-bearing solutions have ponded, typically along the boundary between transported and *in-situ* regolith (the T/I boundary). The fourth facies forms fillings along cracks in transported and *in situ* regolith and fracture-fillings in saprock/bedrock. The regolith profiles and regolith-landform toposequences indicate that the regolith carbonate facies vary both vertically within a profile and laterally across the landscape. The number and thickness of carbonate-rich "horizons" varied widely possibly due to multiple episodes of calcrete precipitation and re-dissolution. In the *in-situ* regolith, the calcrete-bearing layer is 1-8 m thick and generally associated with the T/I boundary, whereas in the transported regolith the calcrete zone occurs as a single near-surface layer, approximately 1 to 3 m thick. Generally, the carbonate-rich layers are within the top 10 m of the regolith (Figure 2).

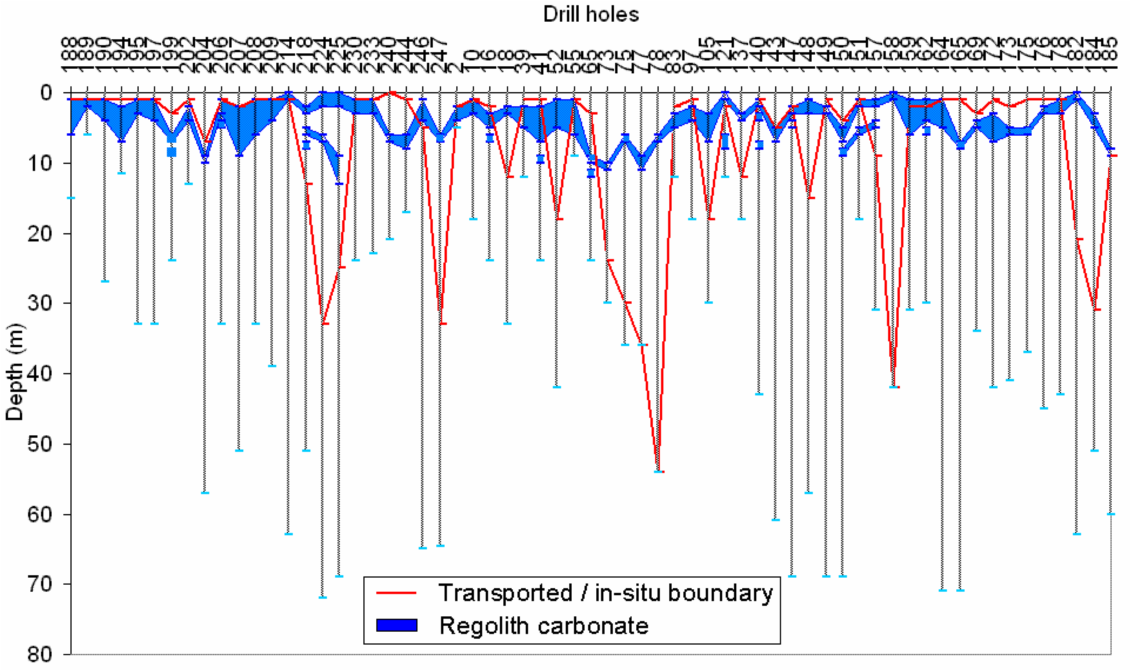


Figure 2: Drill hole plots showing the transported/*in-situ* boundary and distribution of calcrete-bearing zones in the regolith of the Girilambone region. Drill hole locations are shown on Figure 1.

REGOLITH CARBONATE COMPOSITION

Regolith samples were analysed by ICP OES following multi-acid (hydrofluoric-perchloric-nitric) digest. Separate sub-samples were analysed for Au by graphite furnace AAS following aqua regia digest and solvent extraction. Compositional variability of carbonate-bearing regolith can be shown using the components MgO, CaO and the major non-carbonate component, Al_2O_3 (Figure 3).

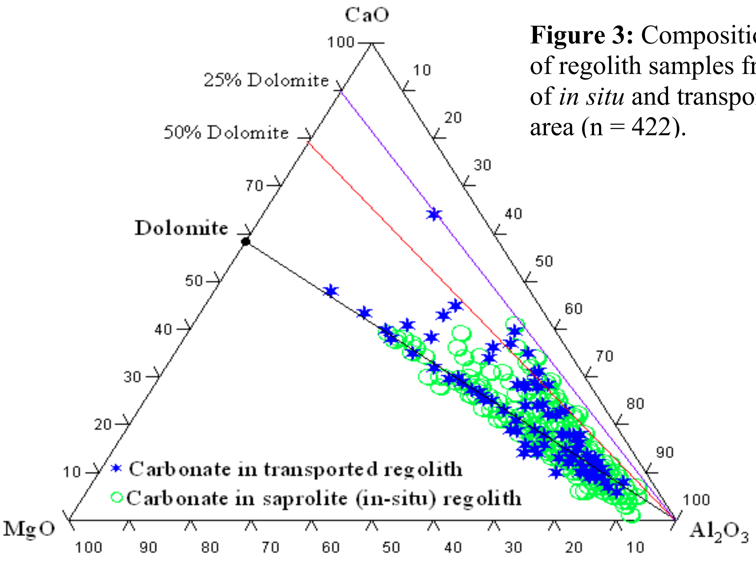


Figure 3: Compositional plot (MgO-CaO-Al_2O_3 wt%) of regolith samples from the regolith carbonate zone of *in situ* and transported regolith in the Girilambone area (n = 422).

The proportion of carbonate in the samples varies from several wt% to nearly pure carbonate. Most samples have a significant non-carbonate component, as reflected by the concentration of compositions towards the Al_2O_3 apex of the ternary plot. All the data show a significant MgO content reflecting both the common presence of dolomite and a non-carbonate contribution of MgO from clay minerals. X-ray diffraction analysis on a suite of samples indicates that there is generally little or no magnesite in the carbonate. There does not appear to be any systematic difference between compositions for calcrete from transported versus *in situ* regolith.

GOLD IN THE REGOLITH CARBONATE ZONE

Previous investigations of exposed calcrete in the Cobar-Girilambone region have indicated a clear association of Au with calcrete (McQueen *et al*. 1999; McQueen 2006). In areas away from known mineralisation, calcrete generally contains less than 0.001 ppm Au (the detection limit). Detectable Au is found in calcrete at sites close to or down drainage from known gold mineralisation, with 0.004 ppm considered a regional threshold and 0.012 ppm a local (deposit) threshold. This work also revealed that the presence of carbonate is an indicator of a geochemical environment conducive to precipitation of chemically mobilised Au. The total carbonate content is probably not a significant control on the Au concentration. Partly for this reason, the bulk regolith samples through the calcrete-bearing layers in the Girilambone region do not always show a clear one to one correlation between Au content and Ca or Mg concentration. The relationship between Au distribution and calcrete development in the Girilambone regolith can be explored further by comparing selected Au-bearing profiles from *in situ* and transported regolith.

Association of Au with calcrete in the *in situ* regolith

Anomalous Au concentrations associated with calcrete from *in-situ* regolith range from 0.005 ppm to 0.025 ppm. Four examples from drill holes CBAC2, CBAC41, CBAC188 and CBAC204 are presented. The saprock/bedrock intersected in these holes consists of laminated siltstone in CBAC41, micaceous siltstone with some quartz veining in CBAC2 and CBAC188, and quartz-mica schist in CBAC204.

In CBAC2 and CBAC188 calcrete has accumulated along and just below the T/I boundary (Figures 3 & 4). The highest Au values in these drill holes do not coincide with the highest Ca or Mg contents, suggesting that the calcrete is not directly accumulating Au. Gold contents also vary within the regolith carbonate zone. In CBAC2 the highest Au content is in the middle of the regolith carbonate zone and is associated with elevated Bi and lower Fe contents (Figure 4). The compositional trends in CBAC2 show elevated Ca in the upper part of the profile, decreasing more rapidly than Mg content with depth. This would be consistent with mixed calcite-dolomite in the upper part of the calcrete zone (1 m) and predominantly dolomite below (2 m). Some of the Mg may be present in non-carbonate minerals such as smectite.

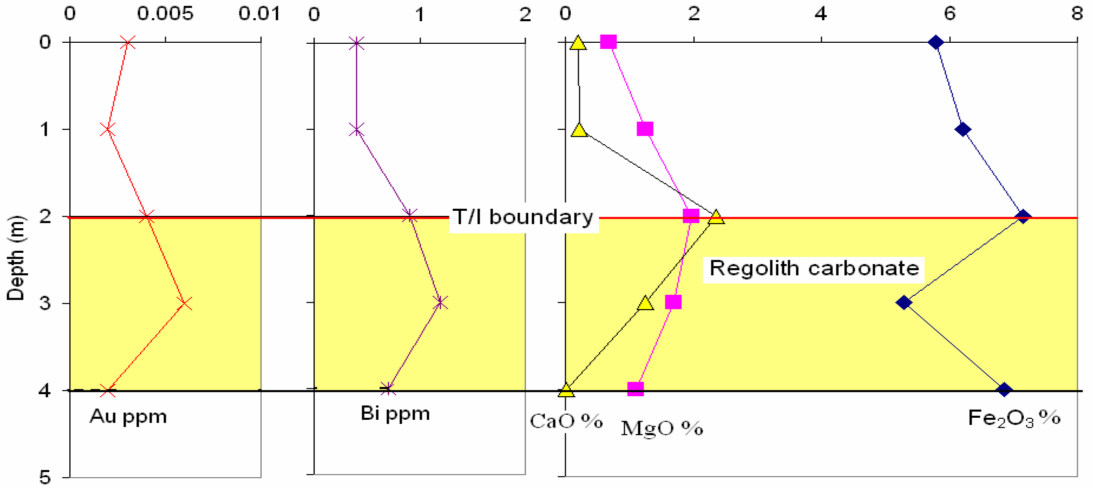


Figure 4: Distributions of Au, Bi, CaO, MgO and total Fe as Fe_2O_3 through the regolith carbonate zone within *in situ* regolith in drill hole CBAC2.

There is also significant Ca enrichment near the top of the regolith carbonate zone in drill hole CBAC188. The Au content increases with depth through the carbonate zone in association with increasing Fe content (Figure 5). This Au-Fe association possibly reflects remnant primary gold mineralisation in the saprolite (W is also elevated) or possibly the influence of pH or a redox boundary related to ferruginisation. Below the regolith carbonate zone at 8 m depth, the gold content increases to 0.026 ppm in association with slightly elevated W (10 ppm), As (31 ppm) and quartz veining. This is consistent with the presence of a remnant primary gold anomaly, possibly partly leached, within the saprolite at this site. The remnant Au may be adsorbed onto hematite/goethite, possibly formed by weathering of primary Fe sulphides associated with gold mineralisation.

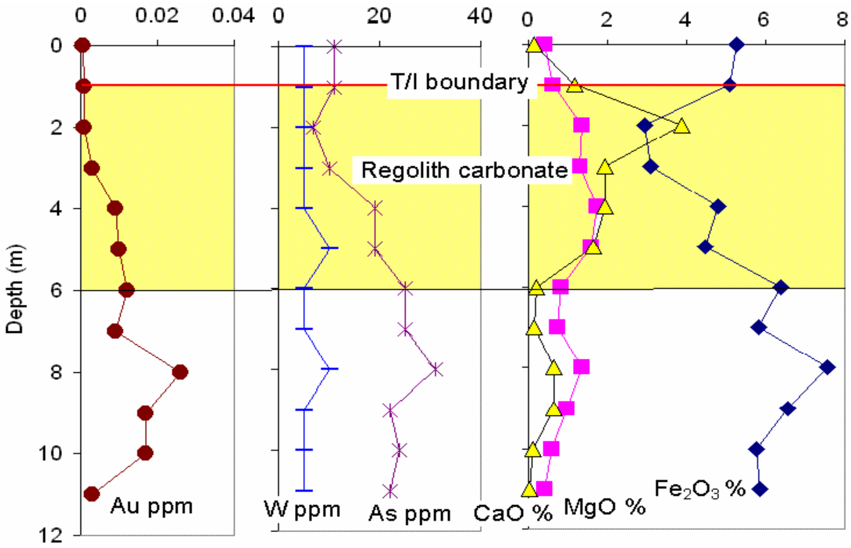


Figure 5: Distributions of Au, As, W, CaO, MgO and total Fe as Fe_2O_3 through the regolith carbonate zone in drill hole CBAC188.

In drill holes CBAC41 and CBAC204, calcrete occurs within *in situ* regolith below the soil or T/I boundary. Elevated gold concentrations in these profiles coincide with higher Ca and Mg contents, which are developed at the top of the regolith carbonate zone. This enrichment is associated with lower Fe content. The compositional trends in drill holes CBAC41 and CBAC204 show that the upper parts of these profiles are more calcite-rich than in the other two examples (Figures 6 & 7).

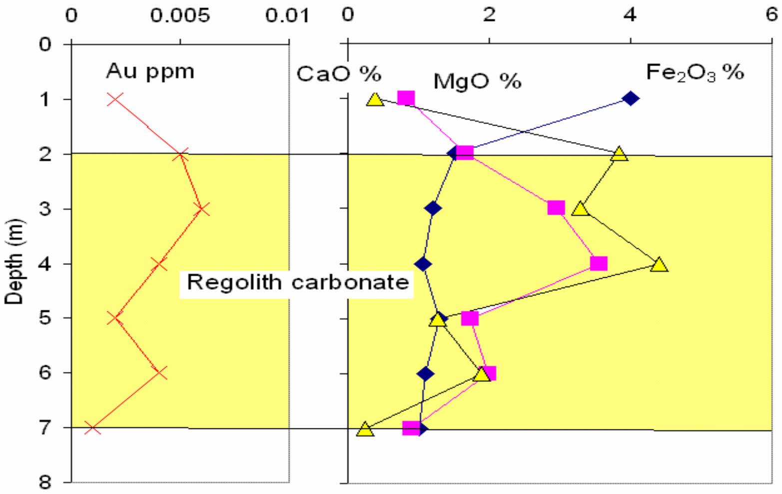


Figure 6: Distributions of Au, CaO, MgO and total Fe as Fe_2O_3 through the regolith carbonate zone within *in situ* regolith in drill hole CBAC41.

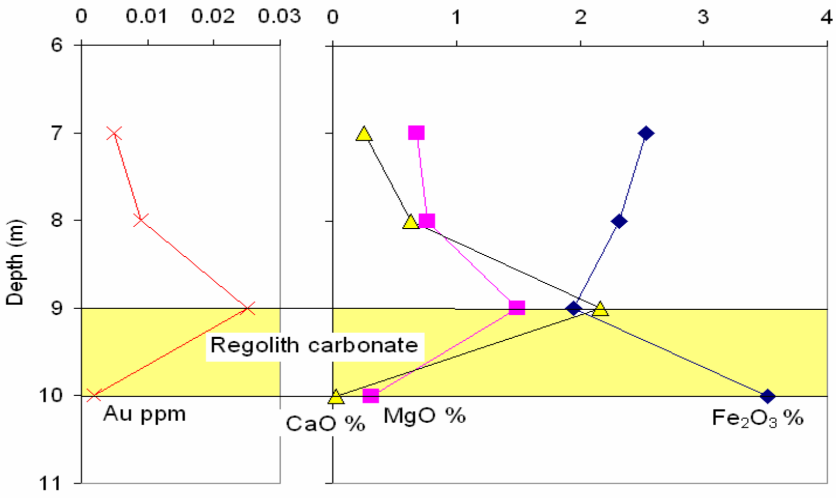


Figure 7: Distributions of Au, CaO, MgO and total Fe as Fe_2O_3 through the regolith carbonate zone within *in situ* regolith in drill hole CBAC204.

Association of Au with calcrete in the transported regolith

Regolith carbonate zones in transported regolith are generally characterised by an upper layer or crust of calcrete. Two examples with elevated Au contents are from drill holes CBAC 78, CBAC 159 (Figure 8). The transported regolith in CBAC78 consists of 24 m of alluvial sand and gravel (with ferruginous clasts) in a recent drainage system, overlying 20 m of lake clays. The profile in CBAC159 has 2 m of silt and clay on top of weathered *in situ* phyllite and sandstone. In both these examples, the highest Au contents occur at the very top of the regolith carbonate zone. In drill hole CBAC78, the top of this zone is at 6 m depth within the transported regolith and has the highest carbonate content as indicated by slightly elevated Ca (1 wt%) and Mg (1.87 wt%) concentrations. The Fe content is lowest in this part, but increases at the base of the regolith carbonate zone (Figure 8A). Given the thickness of transported regolith, the gold concentrated in the regolith carbonate zone in this profile has probably been mobilised from the transported sediment.

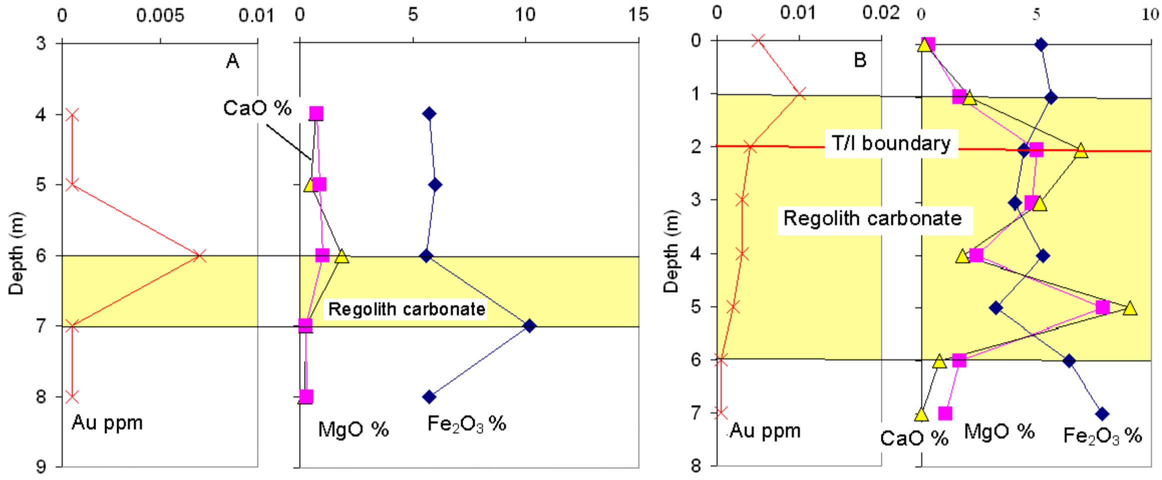


Figure 8: Distribution of Au, CaO, MgO and total Fe as Fe_2O_3 through the regolith carbonate zone within transported regolith in drill hole CBAC78 (A) and across the transported/*in-situ* boundary in drill hole CBAC159 (B).

In drill hole CBAC159, the regolith carbonate zone extends across the T/I boundary. In the *in-situ* part, there are two carbonate-rich levels (at 2 and 5 m depth) as indicated by Ca and Mg concentrations. The upper level coincides with the T/I boundary. Neither of these levels coincides with the highest Au content in the profile, which is within transported regolith at the top of the regolith carbonate zone. The Au content decreases steadily down through the regolith carbonate in the *in situ* part of the profile. The overlying soil contains 0.005 ppm Au (Figure 8B). Again the Fe content is negatively correlated with Ca and Mg contents. X-ray diffraction analysis confirms that calcite is present in the upper part of the regolith carbonate zone, with dolomite dominating in the lower part. In this profile the Au concentrated with calcrete within the thin transported layer has probably been derived from the underlying saprolite.

The presence of several levels of calcrete in these profiles suggests multiple stages of carbonate precipitation, including prior to and after deposition of thin alluvium/colluvium, and after deposition of thicker alluvium in the present/recent drainage systems.

CONCLUSIONS

In the Girilambone region, calcrete is widespread within a zone of variable thickness in the upper 10 m of the regolith. The calcrete typically consists of dispersed calcite-dolomite, generally with calcite predominating in the upper part of the zone and dolomite predominant towards the base. The highest Au contents in a profile are not necessarily associated with the position of maximum calcrete development. Typically, the highest Au concentration is at the top of the calcrete zone, but not in all cases. There is generally a negative correlation between elevated Au and Fe_2O_3 content in this part of the regolith. Some *in situ* profiles show an association of elevated gold with higher Fe_2O_3 content, but this is probably remnant primary Au in ferruginised saprolite.

The association of Au with calcrete in the Girilambone region appears to reflect a chemical environment within both transported and *in situ* regolith that is conducive to precipitation of both carbonate and mobilised gold, rather than a direct control on gold fixation by calcrete. Sampling the regolith carbonate zone, particularly the upper part, should be as effective for detecting mobilised gold anomalies as sampling the calcrete itself.

We recommend sampling the upper part of the regolith carbonate zone within shallow transported and *in situ* regolith during air-core drilling, as part of the strategy for gold exploration in this region. Identifying this zone from drill cuttings in the field is probably best done by testing samples with hydrochloric acid and careful visual observation. This can be verified from the Ca and Mg contents of samples, following chemical analysis.

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