

RECONCILIATION – DELIVERING ON PROMISES

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ABSTRACT

International Codes for the public reporting of Mineral Resources and Reserves are becoming clearer about defining the expectations of shareholders who invest in mining companies. There are trends to more clearly define requirements for annual reporting and for reconciliation of estimations. For example, recent updates to the JORC Code have addressed the concept of quantification of risk associated with estimations and the ASX Group which controls listing of Australian companies now requires listed companies to provide reconciliations of production with previous estimates, mandatory as of December 2013.

Reconciliation will increasingly become the benchmark by which mining company performance is judged, based on comparing actual production with predictions (promises). This paper outlines the objectives, principles, processes and practice of a robust reconciliation program. Reconciling from the resource through to delivery of a mineral product is the key to adding value during development of a mining project.

INTRODUCTION

Mining Geology, Grade Control and Reconciliation

The ideas and approach presented here are based on the lead author's practical experience on many mine sites in employee and management roles, subsequent consulting experience of more than 20 years, the training of over 1000 mining personnel in a workshop course titled with the subheading above (Shaw, 1991) and analysis of hundreds of mining projects.

Nevertheless, while the proposed approach is simple, it has profound consequences. Reconciliation has until now been very much a 'black art' with every young mining professional coming up with new, sometimes novel solutions (and spreadsheets) when faced with the ubiquitous questions: "Where have the ore tonnes gone? Why is the grade not what was expected? What has happened to the metal balance?"

The objective here is to provide some guidance to understand what needs to be addressed, how it can be done and the consequences of doing reconciliation well.

RECONCILIATION PRINCIPLES

A Question of Accuracy (And Reporting)

The authors are familiar with reconciliation procedures and practices in major mining companies such as BHP Billiton, Anglo American (Chile), Codelco and Newmont, all of which have multiple large operations. Consistency within these companies in their reconciliation practices means that the metrics developed are useful company wide. In detail the practices differ and there is obvious benefit in developing one approach that can eventually provide consistent industry-wide comparisons.

In developing procedures to protect investors, and to ensure that the estimates are based on sound data and practices, organisations such as the Joint Ore Reserves Committee in Australasia, and similar bodies in Canada, South Africa, Europe and Chile have codified the expectations for the quality of these estimates by defining terms such as Measured Mineral Resources, Proved Ore (Mineral) Reserves, and the other three permitted classes of Indicated, Inferred and Probable (e.g. Jorc, 2012). The definitions for these classes, promulgated by the international body CRIRSCO (2013), are now well understood, consistent and useful.

Attempts to move from qualitative, subjective classification of resources and reserves to more quantitative objective measures has been slow but will no doubt continue to be explored. The 2012 JORC Code has some requirements in Table 1 (Section 4) for the soon to be mandatory 'if not, why not' reporting in Australasia of all aspects of the preparation of Ore Reserves¹. Table 1 now includes the following guideline (Jorc, 2012):

"Where appropriate a statement of the relative accuracy and confidence level in the Ore Reserve estimate using an approach or procedure deemed appropriate by the Competent Person. For example, the application of statistical or geostatistical procedures to

¹ A similar clause in Table 1 (Section 3) relates to Mineral Resources if for some reason these are not included in the Ore Reserves.

quantify the relative accuracy of the reserve within stated confidence limits, or, if such an approach is not deemed appropriate, a qualitative discussion of the factors which could affect the relative accuracy and confidence of the estimate.

- *The statement should specify whether it relates to global or local estimates, and, if local, state the relevant tonnages, which should be relevant to technical and economic evaluation. Documentation should include assumptions made and the procedures used.*
- *Accuracy and confidence discussions should extend to specific discussions of any applied Modifying Factors that may have a material impact on Ore Reserve viability, or for which there are remaining areas of uncertainty at the current study stage.*
- *It is recognised that this may not be possible or appropriate in all circumstances. These statements of relative accuracy and confidence of the estimate should be compared with production data, where available.”*

Note that the last sentence encourages reconciliation between predictions (Ore Reserves) and production.

Nevertheless, the ASX Group has added additional reporting requirements to their ASX Listing Rules, also mandatory from 1 December 2013, which include (ASX, 2013a):

“5.21.4 A comparison of the mining entity’s mineral resources and ore reserves holdings against that from the previous year on the following basis:

- by commodity type, including the grade or quality; and
- total ore reserves and total mineral resources by geographical area based on the materiality of the mineral resources and ore reserves holdings to the mining entity,

including an explanation of any material changes in the mineral resources and ore reserves holdings from the previous year.”.

These rules are elaborated on in Guidance Note 31 (ASX, 2013b) as follows:

“A mining entity should report its mineral resource and ore reserve holdings as at the same time each year to promote effective year-on-year comparisons.

The annual mineral resources and ore reserves statement must include a comparison of the entity’s reported aggregated mineral resource and ore reserve holdings for the current year against the corresponding aggregated mineral resource and ore reserve holdings for the previous year, with an explanation of material changes between the two” (based on 2013 Listing Rule 5.21.4.). “For the purposes of this comparison, ASX does not require the mining entity to disclose the previous year holdings broken down into each mineral resource category and ore reserve category (such as probable ore reserves and proved ore reserves). The comparison only needs to be provided by commodity (including grade or quality) for total ore reserves and total mineral resources and by project (if material) or geographic region based on materiality.”

This is a specific requirement for comparison of the current Ore Reserve statement with the previous one.

It can be seen that the mining industry is moving, albeit gently, towards the concept of consistent reporting of reconciliations as a further way of protecting investors in mining companies.

Defining Reconciliation

Reconciliation is the process of comparing predictions to actual production; it does not of itself generate errors, but it can identify the net impact of the errors in the process.

Reconciliation is not necessarily the determining test as to whether the ‘mine is successful’. A mine may be profitable even if it is based on a poor mineral resource, a poor ore reserve (which includes mine planning practices), or poor mining or processing practices. Reconciliation is not even a test of whether the ore blocking and other grade control practices are optimal, with one exception to be discussed below in **Grade Control (prediction) constraints on Reconciliation**.

Reconciliation is a scientific and objective method to determine whether the assumptions built into your predictions are valid. It can be used to:

- increase the accuracy of forward planning
- improve knowledge of the ore body
- explain problems
- justify improvements to current practice.

Reconciliation is not accounting. The objective is not to get two sets of numbers to balance, which is often seen as an end in itself by those focused on factors. However metrics such as factors are extremely useful if developed consistently and used as the basis for a continuous improvement programme.

In fundamental terms reconciliation involves the comparison of outcomes (production) against predictions (estimates). In the simplest case the shareholders want to see a comparison between the annual net revenue for the mine compared to the predictions made to them at the end of the Feasibility Study. Defining this question more tightly, they want to know there are comparisons of production against predictions for ore and metal produced over consistent volumes and time periods. A robust quantitative reconciliation method is required to do this.

The most useful concept of reconciliation is that of Ore Reserve (prediction) to Grade Control (prediction) to Mining (production) to Milling (production). This process is examined further below.

THE RECONCILIATION PROCESS

Ore Reserve (prediction) constraints on Reconciliation

Mineral resource models are invariably produced now as computer block models. The constraints on these are the sparsity and quality of the input data (geological mapping and logging, sample preparation and assaying, etc.) and the subsequent geostatistical modelling (anisotropy, boundary effects, smoothing, etc.).

Converting the mineral resource to an ore reserve requires a mining plan and includes consideration of various ‘modifying factors’ (e.g. JORC, 2012; CRIRSCO, 2013).

Many differences between the Ore Reserve predictions and the subsequent Grade Control, Mining and Milling components of the reconciliation chain stem from an incorrect understanding of how geostatistical concepts of block size, panel size and selective mining unit (SMU) relate to actual mining practices. Previous papers by the authors discuss ways to model these such as the Chain of Mining approach (Khosrowshahi and Shaw, 2001; Godoy *et al.*, 2006) and to reflect them in resource/reserve classifications (Shaw *et al.*, 2006).

Grade Control (prediction) constraints on Reconciliation

The grade control (or ore control) process involves the predictive delineation of the tonnes and grade of ore that will be recovered by mining. The predictions have a number of common characteristics across all mineralisation and mining types, from small, low production rate, metalliferous underground mines to large world-class open pits, as two diverse examples. The common characteristics of grade control prediction at all operations are: i) abundant geological data that may have only minimal relevance or may not be used; ii) abundant sampling data that may be of relatively poor quality (e.g. have significant sampling errors); and iii) production pressures requiring fast interpretation of the data and rapid prediction of the ore blocks.

Prior to mining, a program of ‘grade control’ sampling is generally carried out to define the boundaries of mineable ore blocks. The amount of sampling is constrained by both practical limitations and cost considerations. All sampling methods incur errors and there are different sampling methods to choose from, including different grid patterns and spacings. Even where a number of sampling methods are attempted, the ore block can only be mined once and so the effects of alternative ore block designs, based on different sampling methods, is not in reality accessible.

Various solutions to consistently estimating and predicting ore block boundaries have been proposed including those by Shaw and Khosrowshahi (2004). When based on conditional simulation these approaches generally include the ability to define ore loss (material above cut-off grade that is not economically recoverable) and dilution (material below cut-off grade that is included within the planned ore blocks). If a risk-based approach is used to defining ore boundaries it is possible to use reconciliation to test whether the ore blocking and other grade control practices are optimal.

Mining (Production) Constraints on Reconciliation

The mining process is central to the issue of comparing production to predictions. It relies on components such as blasting, digging, hauling, stockpiling and delivering the ore to the mill.

Once the ore block is designed, it is in most cases blasted before mining. This imposes a variable movement on the ore, made up of components of heave and lateral displacement. Such movements are not necessarily consistent due to local geology, drill hole characteristics and the dynamic nature of blasting. The ore block design must be re-established on the broken ore, and errors will be incurred in doing this. The broken ore is then dug using the ore block boundaries, and possibly visual controls on mineralisation, as guides. The mining equipment may be large and the ore block boundaries will contain corners. Mining errors will thus occur. This open pit scenario has parallels in underground mining with over-break and hang-ups in stopes.

Mined ore may be sent for treatment directly to the mill or to stockpiles. Uncertainty in the grade of stockpiles can result where the cut-off grade varies over time, or where a 'last-in, first-out' policy exists, resulting in unknown material remaining on the stockpile.

Routine reconciliations must be carried out and ideally, acknowledging the difficulties in obtaining reliable data, these should be based on estimates of:

- Volumes, tonnes, grade, density and moisture content of ore actually mined
- Identification of any ore that is additional to that predicted by the grade control planning, whether selected either visually or by rehandle sampling
- Identification of misallocation of ore and waste as deviations from the grade control plan (planned ore sent to waste, planned waste sent to the mill)
- Surveyed volumes of the mined pit benches (or stopes)
- Truck tonnages (often based on truck factors)
- Stockpile movements.

The importance of using best available practice for all these components has been stressed in many forums and is not further examined here.

Milling (Production) Constraints on Reconciliation

Definition of the actual metal production commonly relies on calculating the metallurgical balance in the mill. Ore treatment is a dynamic process and there is an accumulation of errors due to sampling, and due to the lag in the mill between feeding ore and calculating milled grades (Siddall and Baxter, 1990; Francois-Bongarcon and Gy, 2002). The common practice of blending ores into the mill, from different orebodies, different parts of the same orebody, or from imperfectly known stockpiles, can add to the uncertainty of the production figures in reconciliations.

Basic Reconciliation Procedures

A simple scientific approach should enable a robust reconciliation method to be quickly developed. The essential steps are:

1. Establish an audit trail for all data

2. Agree to report results routinely in a consistent format and ensure that there are cross-functional reconciliation meetings in place to discuss results and develop action plans
3. Tabulate the data
4. Report variations based on consistent volumes (bench by bench, stope by stope) or periods (monthly, quarterly, annually)
5. Graph the variations (or factors) for each parameter to determine trends
6. Analyse the differences and annotate the graphs to explain the differences
7. Alter the input parameters systematically to reduce future reconciliation differences.

The Ideal Case

In an operating mine, reconciliations are generally done progressively by accumulating predictions for treated ore and comparing them to the production (mill) results (Shaw, 1991; Wild, 1998). Unfortunately, reconciliations can be rendered equivocal when it comes to evaluating the success of the grade control process, due to errors in the grade control, mining and treatment practices.

A more sophisticated approach using an analysis of the errors in the Chain of Value was outlined by Shaw *et al.*, (2002). This was developed as part of a mass balance study for an integrated base metal operation that comprised a number of mines, open pit and underground, a concentrator, refinery and smelter. The entire operation was regarded as a business unit and profit centre. While overall reconciliation between the Ore Reserves and the Production (metal delivered) was simple enough, the source of the identified problems was obscured by blending at many points in the process and by the lack of consistent data collection and management of that data. One part of the solution was to identify the errors at specific points in the Chain of Value and then to develop procedures to reduce these, or nullify them in some cases using multiple sources of information that accounted for redundant data.

RECONCILIATION PRACTICE

A Consistent Framework for Factors

Mine call factors and mill call factors have been used in many mines without any clear systematic definition. Harry Parker recently provided a useful framework based on his extensive work in estimating and auditing ore reserves. In doing so Parker (2012) has provided a solution to many of the grade control reconciliation problems, since by his definitions, if:

$$F1 = \frac{\text{short range model depletions}}{\text{long range model depletions}} \text{ ie } F1 = \frac{\text{GRADE CONTROL (PREDICTION)}}{\text{ORE RESERVE (PREDICTION)}}$$

and

$$F2 = \frac{\text{received at mill}}{\text{delivered to mill}} \text{ ie } F2 = \frac{\text{MILL (PRODUCTION)}}{\text{GRADE CONTROL (PREDICTION)}}$$

and

$$F3 = \frac{\text{received at mill}}{\text{long range model depletions}} \text{ ie } F3 = \frac{\text{MILL (PRODUCTION)}}{\text{ORE RESERVE (PREDICTION)}}$$

then it is now obvious that $F3 = F1 * F2$

By ensuring that reconciliations are all done as factors (for tonnes, grade and metal) and that each stage of the chain is used as the numerator when compared to the previous component in the chain, all the various components of a mine reconciliation scheme can be rationalised and compared.

Note that in the above formulae as reinterpreted on the right side in this paper, the Grade Control (prediction) step is equated with both the *short range model depletions* and the *delivered to mill* steps of Parker (2012). This is acceptable in that the intermediate steps of the reconciliation process can be considered as a black box when there is insufficient good data, so that the intermediate factor (F2 in this case) can be constrained.

The reconciliation chain proposed by Parker can be elaborated on (and often is in operating mines) as shown in Figure 1 and Table 1.

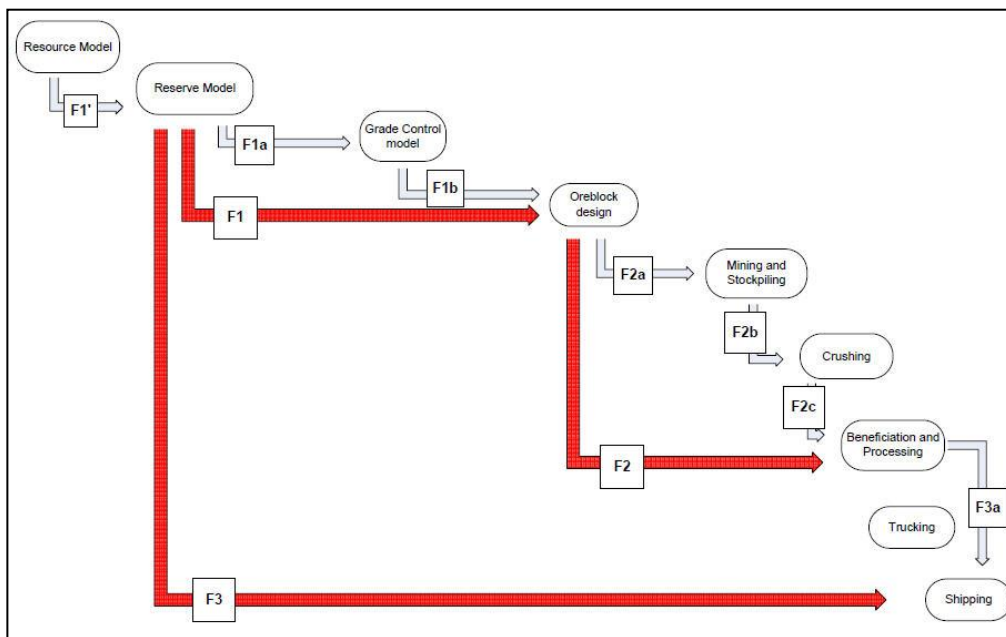


Figure 1 - Elaboration of the reconciliation process defining additional steps.

Table 1 - Typical inputs into the reconciliation value chain shown in Figure 1.

Reconciliation Stage	Used in Factor	Subcomponents	Data Inputs
ORE RESERVE (prediction)	F1 and F3	Mineral Resource model mine plan geometallurgical parameters expected mill recovery	resource model exploration data original topography mining surface (start) mining surface (end)
GRADE CONTROL (prediction)	F1 and F2	F1a short term model	geological mapping grade control sampling
		F1b planned ore blocks and/or designed stopes	ore block polygons stope design grade and density estimation geotechnical criteria mining widths and efficiencies
MINING (production)	F2 and F3	F2a digging	blast movement ore and waste haulage
		F2b stockpiling	truck counts and surveys
		F2c crushing	weightometer
MILLING (production)	F2 and F3	F3a beneficiation	processing records metal balance
		shipping	surveys metal sales.

Note that Parker (2012) refers to F1a as F' and to F1b as F''.

It is evident from this approach that the reconciliation process for any operation can be systematically and consistently analysed. The reconciliation chain may well be different for different operations but within the chain the use of factors and consistently using the denominator for the earlier part of the chain enables errors and assumptions to be controlled, mitigated or accumulated.

Figure 2 provides an example of a graph of the F1 reconciliation (grade control vs ore reserves) for an open pit gold mine. Note the ±15% tolerances (red dotted lines) on tonnes, grade and ounces as well as annotations where changing trends suggest that there may be issues to investigate.

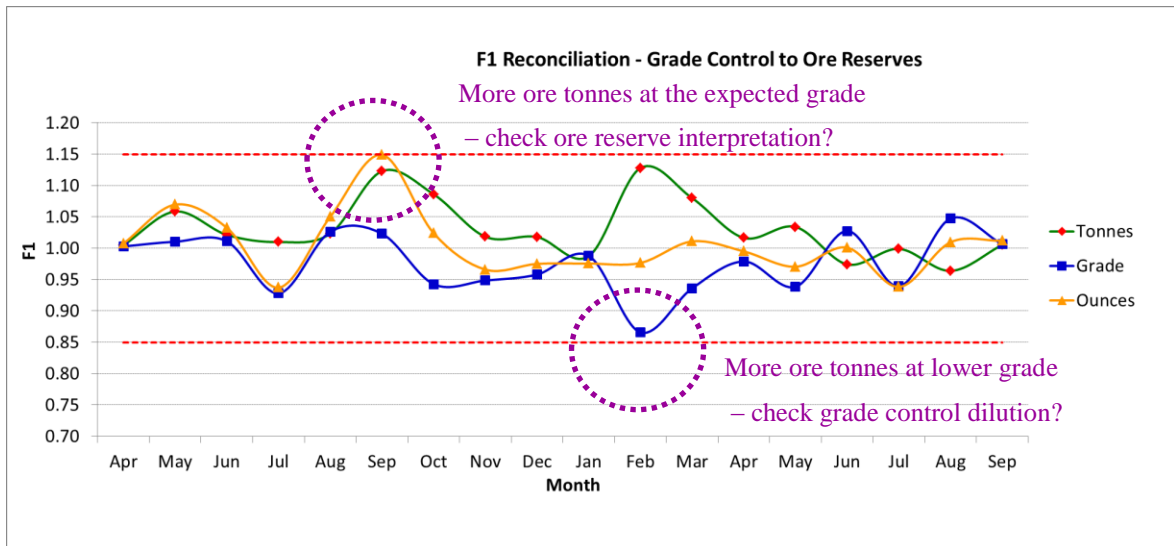


Figure 2 - An example of an annotated F1 reconciliation graph for an open pit gold mine.

One Solution to the Problem of Uncertainty in Reconciliations

Relying on reconciliations based on unclear data has created obstacles to the objective assessment and improvement of grade control techniques at many operating mines. Comparisons of methods can be carried out, but assertions about the relative benefits of different methods cannot be tested.

If a model of an orebody is created, the grade control, mining and milling processes can then be modelled. For example, the orebody model can be sampled using various grade-control strategies and then these notional grade-control samples can be used to predict outcomes. Such predictions can be compared to the complete model (the exhaustive data set) from which the sample set is extracted. Where such approaches are based on conditional simulation modelling they have the advantage that the transfer function used to interrogate the model can be transparently and objectively manipulated to seek different outcomes and provide a way for the Grade Control and Mining processes to target the Ore Reserve predictions.

Other Types of Reconciliation

There are many comparisons worthy of examination as part of the continuous improvement process, or for that matter during a mine audit. The concept of comparing Actuals with Predictions, and reporting variances (or more preferably variations) can be applied to many aspects of the mine performance, including but not limited to: tonnage, grade, metal, moisture, density, costs, revenues, energy consumption, efficiency, and even meeting statutory obligations.

Less evident but also extremely useful are spatial reconciliations such as comparisons of geology (mapping vs early interpretations) and mine planning (the areas actually mined vs areas proposed in the mine plan). An example of a spatial reconciliation of the grade control ore blocks overlain on the ore reserve predictions is shown in Figure 3. It is apparent from this figure that there is little congruity between the shapes or areas of the ore reserve polygons (the elongate smooth east-west outlines) and the grade control polygons (the angular more discrete blocks with tracking code numbers on them). This is not unusual and may be due to the sparsity of the exploration data, the quality of the grade control sampling and the section/plan interpretation method that was used for the grade control interpretation.

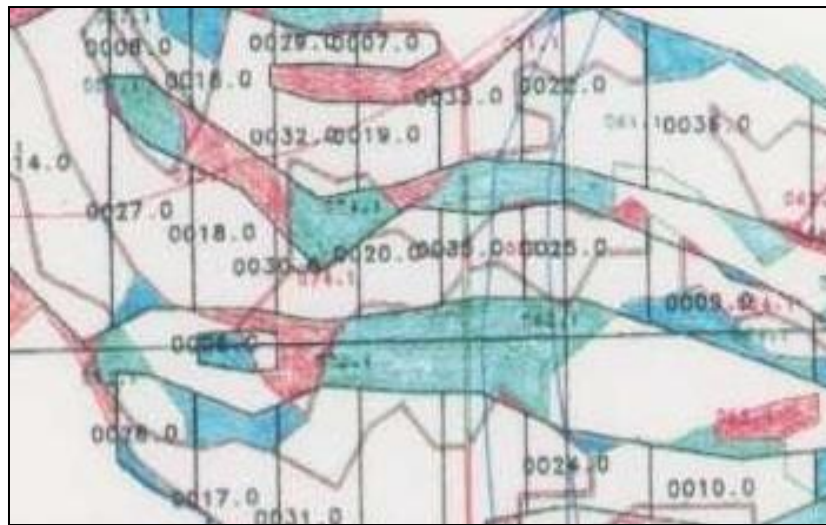


Figure 3 - A spatial reconciliation of predicted grade control blocks versus the predicted ore reserve blocks. Blue is where the model successfully predicted ore; red is where the predicted ore was found to be low grade. White regions are where waste and ore were incorrectly predicted by the ore reserve model.

Outcomes of a Robust Reconciliation System

Reconciliations should be consistently monitored over time. A successful predictive approach can deteriorate due to changes in geology, ore type, sampling procedures, grade control methods, mining methods, milling controls, personnel, etc. Lack of systematic reconciliation means that there are no controls to monitor the predictions, and to moderate expectations. This may result in non-optimal use of the resource, pressure on the mining team, profit objectives not being met and unhappy shareholders.

Recognition of trends can provide insight into how the current predictions may become realised during future production. It is useful to know that the mill is receiving the predicted ore at a lower than expected grade, even while there is still uncertainty as to whether this is due to problems with the ore reserve (due to data, interpretation or estimation), with the grade control (due to similar errors plus ore loss and dilution), with mining (due to deviations from the plan)

or with milling (due to sampling errors or losses). Similarly it is useful to know that production is exceeding predictions since this may mean the grade control process, the mine plan and the revenues are all suboptimal.

CONCLUSIONS

A robust reconciliation system enables the total mining operation to be seen in context, major problems and sources of error to be identified, both underestimation and overestimation to be critically monitored, improvements to be tested and evaluated, and reporting to management and communication to shareholders to be clear and consistent.

Reconciling from the resource through to delivery of a mineral product is the key to adding value during development of a mining project.

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