

Anglo American Platinum's approach to resource classification case study—Boschkoppie/Styldrift minewide UG2 project

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The classification of mineral resources is often a team effort with specific team members delivering assessments of the resource based on their relevant discipline input into the resource estimation process, for example structure analysis, borehole logging, database management, quality control and quality assurance and resource estimation. It is essential that the mineral resource classification takes all these measures of confidence and uncertainty into account in determining the overall resource confidence and hence classification. The approach adopted needs to be relevant, transparent, repeatable and defensible. The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC code, 2007) expresses the need for the Competent Person to consider all the criteria listed in its Table I when reporting mineral resources.

This paper describes the approach adopted by Anglo American Platinum Limited (APL) in the classification of their mineral resources in the Bushveld Complex UG2, Merensky Reef, Platreef and along the Great Dyke in Zimbabwe.

Introduction

All too often resource classifications are based solely on the confidences ascribed to the geostatistical estimates for grade and/or width and/or density, simply because these estimation confidence statistics are available in the estimation models. The confidences associated with non-geostatistical elements such as structural interpretation, geological loss, mining history, quality control, domain and facies segregation are often ignored or given token acknowledgement. This is usually because insufficient work has been undertaken to qualify and quantify the confidence in the elements associated with the geological aspects that play a role in resource estimation and implicitly the resource confidence.

APL reports all resources (measured, indicated and inferred) according to the South African Code for Reporting of Mineral Resources and Mineral Reserves (SAMREC Code, 2007) and the Australian Code for Reporting of Mineral Resources and Ore Reserves (JORC code). APL has applied the considerations of SAMREC's Table I in a standardized resource classification procedure which has been applied to all estimation models that could be either two or three dimensional and have been created through the application of kriging methods. The procedure assesses the confidence associated with the orebody geology, geometry and the estimation results on an estimation cell by cell basis taking cognizance of the relative importance of these elements to the particular resource. The confidence in each relevant non-geostatistical element is spatially assigned a high, medium or low confidence. The confidence is applied to the model cells and once weighting parameters have been applied, a weighted average confidence is determined per

model cell; the weighted average confidence is then translated into one of the three resource categories. The spatial position of the non-geostatistical element's polygons, their confidence codes and the weightings may be interactively varied to assess their impact on the classification.

The procedure provides documented support for the classification adopted and the rationalization of the diverse qualitative and quantitative attributes of the elements considered. The relevant elements and the weighting parameters are recorded and are reported once the classification has been finalized. As the application of the process is mechanical it is important that the overall classification be reviewed by the Competent Person (CP) on a global basis to refine the confidence boundaries. This means that the final classification of the resource truly takes into consideration all elements relevant to that resource and also the experience of the CP. In APL, the resource classification process is documented for each resource assessment in a report which records the classification parameters, discussions and refinements and the final classification is accepted and signed off by the Competent Persons Team (CPT). This method of classification is an example of an auditable, transparent, reproducible methodology which embraces the full spectrum of geological knowledge built up during the exploration and exploitation of a resource.

Procedure

All elements are assigned two standardized attributes, a colour code and a numerical code. The colour codes are used for visual displays on plans or when superimposing

polygons over the model. The geostatistical outputs are assigned the confidences according to the standard threshold limits applied across the group. The confidence categories for the non-geostatistical elements are assigned to the estimation model cells through a process whereby the numerical code of the polygons are 'stamped' onto the model cells. The colour and numerical codes are applied as follows:

- Red represents high confidence
- Green for medium confidence
- Blue for low confidence.

For calculation purposes, each of the elements has a numerical code applied where:

- 1 represents high confidence
- 2 for medium confidence
- 3 for low confidence.

The procedure is driven by three steps:

Step 1

The non-geostatistical elements relate to the understanding of the mining history, structural interpretation, quality assurance and control (QAQC) of all data, geological loss determinations and domain/geozone interpretations. A set of up to three categories of polygons is constructed for each element that represent the confidence in the areas encapsulated. The location and confidence ascribed to each polygon draw on the specific knowledge of the appropriate geological team members. It is important that the polygons applied are considered as 'confidence polygons', i.e. they indicate areas of greater or lesser confidence. This should not be confused with complexity or scale—thus an area of high geological loss may be encompassed by a high confidence polygon if the interpretation of that area is well supported by high quality data. Once the polygons have been defined, only minimal changes year on year should be required for subsequent resource classifications.

Step 2

Up to two of the fields estimated into the resource model can be identified for use in driving the geostatistical elements of the classification; normally the most important grade or grade and width would be selected (or grade and density if the resource grade is over a constant width). In accordance with the company standards, the kriging confidence statistics are assigned the colour and numerical values as described above. This standardization is possible since all the variograms are modelled using a normalized variance. The company's modelling procedure requires that a kriging neighbourhood study be conducted to ensure that appropriate cell dimensions and estimation parameters are adopted. The elements associated with each kriged entity are: the search volume (where the first search volume is equivalent to the variogram range of the element); the number of samples used in the estimate; the kriging variance; the kriging efficiency; and the regression slope. Whereas the kriging efficiency and regression slope are based on input from the kriging variance, they do report slightly different confidence aspects—particularly if different cell sizes have been used in the resource model. It is acknowledged that these confidences are relative. The thresholds for the number categories of the geostatistical elements are:

- Search volume—ranked values assignment are: first search radii = 1; second search radii = 2; third search radii = 3
- Number of samples used by the kriging process—the

range between the minimum and maximum number of samples is divided into three and assigned values of 1, 2 and 3 where 1 would represent the maximum number of samples interval.

- Kriging variance ranking—this is based on the standardized kriging variances (KV). Ranked values assigned are: where $KV < 0.2$, the ranked value is given a value of 1; where $0.2 \leq KV < 0.4$, a value of 2 is assigned; and where $KV \geq 0.4$, a value of 3 is applied.
- Kriging efficiency ranking ($KE = ((BV - KV) / BV)$), where BV is the block variance. Ranked values assigned are: where $KE \geq 0.5$, the ranked value is given a value of 1; where $0.3 < KE < 0.5$, a value of 2 is assigned; and where $KE \leq 0.3$, a value of 3 is applied.
- Regression slope ranking ($RS = (BV - KV + LG) / (BV - KV + 2LG)$), where LG = Lagrange multiplier. Ranked values assigned are: where $RS \geq 0.6$ the ranked value is given a value of 1; where $0.2 < RS < 0.6$, a value of 2 is assigned; and where $RS \leq 0.2$ a value of 3 is applied.

Step 3

The third step is to create a weighting file that defines how significant the elements are relative to one another and to the particular orebody. Having produced plans showing the element colour coding and polygons locations in the preceding steps, it should be clear whether the confidences associated with the model are inherently more grade or structurally biased. For example, an orebody such as the UG2 may have relatively stable grade, density and width characteristics, but could have significant structure or geotechnical uncertainties; in this case the weighting file would emphasize the importance of the non-geostatistical elements. Resource models for the same reef but different properties may have slightly different nuances resulting in slight differences in the weightings parameters applied. The weighting parameters have the useful property of being able to discount the impact of one or more elements entirely (by setting the weight to zero). When deciding on the weights, the following considerations are assessed:

- How is this element going to instil confidence in the qualification and quantification of the resource ounces and tonnages?
- How does this element rank against the others? Is it more or less important?
- Is the element applicable to the orebody environment? For example, the aeromagnetic survey over a deep seated resource, while providing near surface information, does not contribute to the structural understanding of the resource at depth; in this case a weight of zero may be deemed appropriate. Only elements that can be applied and measured should be used in the consideration.

The weighted scores of up to 17 elements are then calculated per model cell and the final classification is determined as follows:

- Where the weighted score lies between 1 and 1.5: then the cell is deemed to be measured
- Where the weighted score lies between 1.5 and 2.5: then the cell is deemed to be indicated
- Where the weighted score is greater than 2.5: then the cell is deemed to be inferred

Considerable effort is expended on the first model classification exercise; for subsequent model generations the weightings, polygons and their confidences should remain relatively static unless new factors come into play.

Notes on the procedure

This procedure enables the Competent Person to demonstrate to peers, reviewers and auditors that all criteria have been evaluated in a classification. The classification methodology allows for an objective assessment of the resource confidence, ensures repeatability and that any classification changes year on year can be ascribed to the addition of specific new confidence enhancing information. The CPT not only critically reviews the polygon definitions and weightings, but also ensures that a uniform standard is applied across the Group.

The procedure has been designed to be run iteratively in real time so that the sensitivity of the classification to the input elements and their weightings can be assessed instantaneously. Experience has shown that the classifications are relatively insensitive to minor changes in the weighting file and more sensitive to the location and confidences assigned to the different polygons. This emphasizes the need for the geological department's collection and interpretation of data to be qualified in terms of confidence.

Some additional benefits derived from this classification approach are that those elements and areas where additional work is required are highlighted. Consequently the scope of work to be applied by the department to these different elements can be optimized and balanced. The classification procedure design is open ended so that additional elements can be added or even combined as may be deemed appropriate in the future.

Case study

In 2009 the UG2 Reef at Boschkopie mining area and Styldrift exploration project area was the focus for a combined minewide prefeasibility study and has been used as a case study to illustrate the use of the classification procedure described above. The UG2 Reef at Boschkopie has been primarily mined by open pits. Underground trial mining of the UG2 Reef in the past 2 years has resulted in the development of two raises (approximately 800 m in total length) located at North Shaft and at South shaft. The UG2 has not been mined at Styldrift; however, a current shaft sinking project is in progress.

Background

The minewide 2 dimensional UG2 Reef resource model for Styldrift and Boschkopie was updated with available drillhole information as of cut-off date 03/12/2008. Underground sampling information from Impala workings was received on 6 August 2008 with an unknown cut off date and unknown QAQC. A total of 923 Impala underground sample sections and 1 293 surface and underground drillhole intersections (including deflections) were used for the resource modelling estimation. The previous model for Styldrift was completed in February 2007 and for Boschkopie in August 2008. An additional 331 drillhole intersections (surface and underground) were used for the model generated in 2009. Data validation and modelling procedures adhered to the APL's standards.

Methodology

The non-geostatistical elements include aeromagnetic survey, seismic interpretation, structural model, geozone interpretation, geological loss estimates, historical data (mining history) and QAQC of data acquisition, management, logging standards and assay. The

geostatistical elements include kriging variance, kriging efficiency, regression slope, search volume and number of samples used by the kriging of each block. In addition, the previous resource classification was also considered. The Competent Person's resource classification assessment has taken into account all the above together with the risk assessments in defining the final classification boundaries.

All elements are quantified into three confidence categories of high (red), medium (green) and low (blue) confidence and assigned values of 1, 2 and 3 respectively. The classification procedure assigns individual weightings to each element and the average weighted value per model cell is then calculated. Note that in this model the resource cut width is variable and the PGE grade and width were modelled as dependant variables, i.e. as $MGT (PGE * WIDTH)$ and $WIDTH$. The classification procedure is then assessed by the CPT and signed off. The following plans (Figures 1–11) show the 17 individual geostatistical and non-geostatistical elements considered for both the PGE accumulation and thickness. Note that the plans showing the number of samples used and the search volume for the accumulation and width are the same, so only the accumulation ones are shown.

Geostatistical elements

See Figures 1–4.

Non-geostatistical elements

See Figures 5–11.

Note: in Figure 9, the high confidence polygon extends around the declines, with the medium confidence extending to the limits of the overlying Merensky workings.

Element weightings

The weighting considerations for the above elements are shown in Table I. The total weighting assigned to non-geostatistical elements is 25% as this is a low grade resource and the variability in reef thickness and grade is considered more important than the non-geostatistical elements.

Raw scorecard classification

The result of the evaluation using the weighting file listed above is shown in Figure 12.

Refined scorecard classification

The CP scorecard assessment of the resource classification (as shown in Figure 12) took into account the following additional criteria:

- Previous classification,
- 500 m blocks were not considered for measured resources (located in areas of sparse drilling information)
- Classification boundary considerations
- Internal 'islands' of higher or lower confidence.

Figure 13 shows the results of the CP's refined assessment.

The CP presented the classification procedure in a standardized format to the CPT indicating the:

- Derivation of the location of the polygons
- The polygon rankings
- The derivation of the weights applied
- The CP assessments applied.

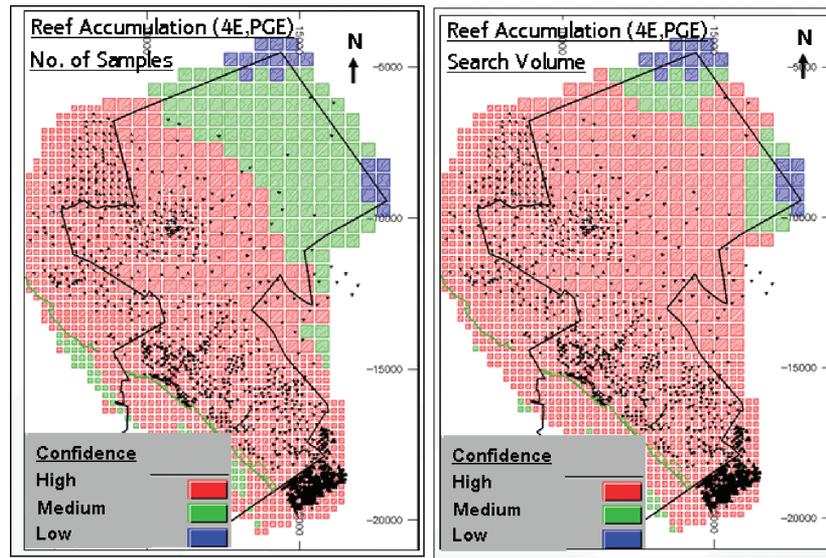


Figure 1. PGE accumulation—number of samples used and search ellipse

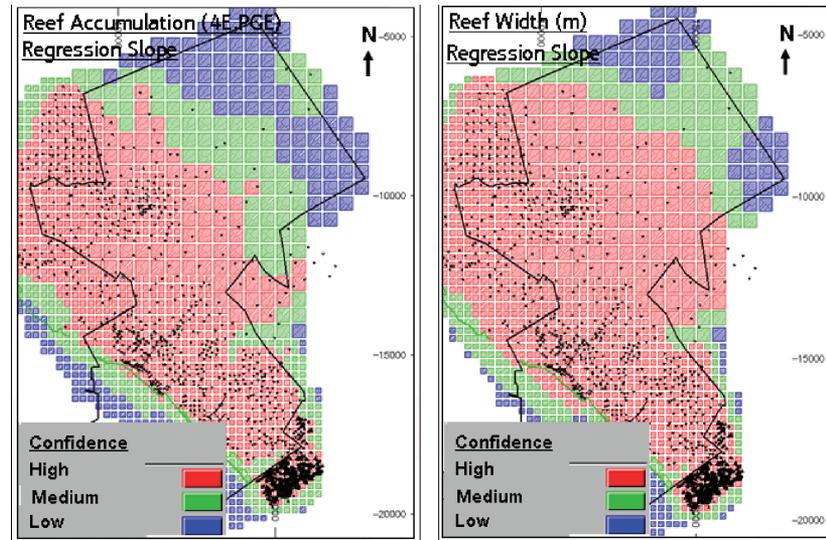


Figure 2. Regression slopes—PGE accumulation and width

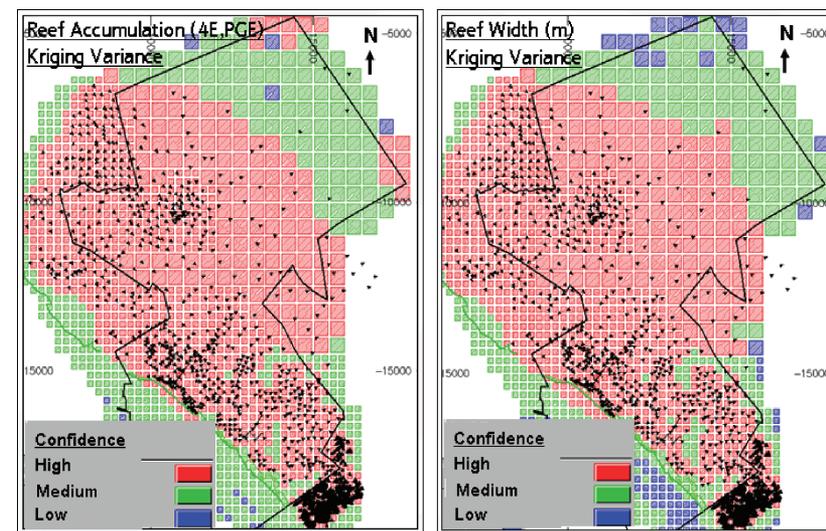


Figure 3. Kriging variances—PGE accumulation and width

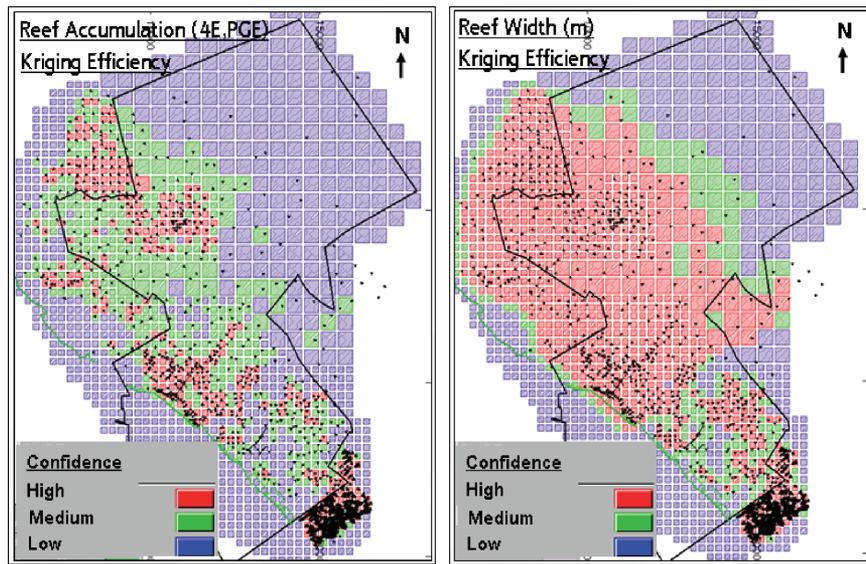


Figure 4. Kriging efficiencies—PGE accumulation and width

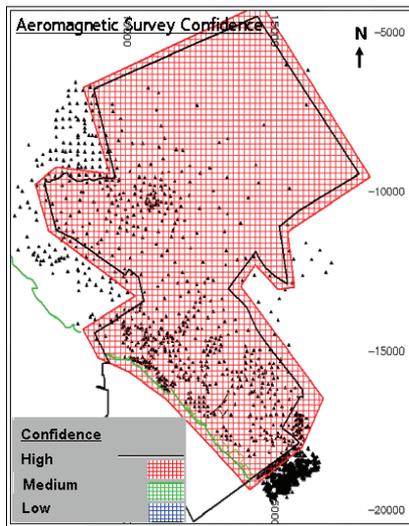


Figure 5. Aeromagnetic survey confidence

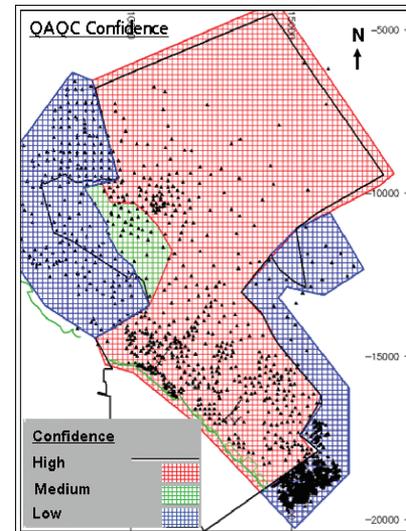


Figure 7. QAQC confidence

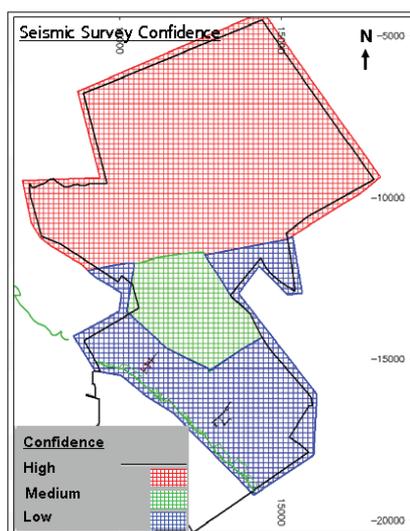


Figure 6. Seismic Survey confidence

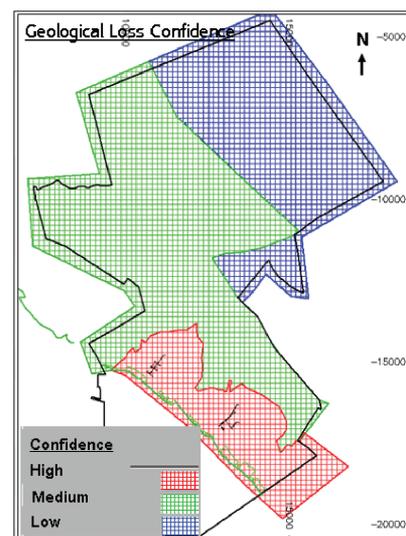


Figure 8. Geological loss confidence

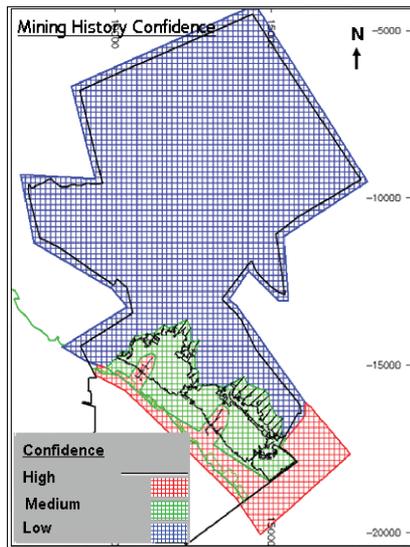


Figure 9. Mining history confidence

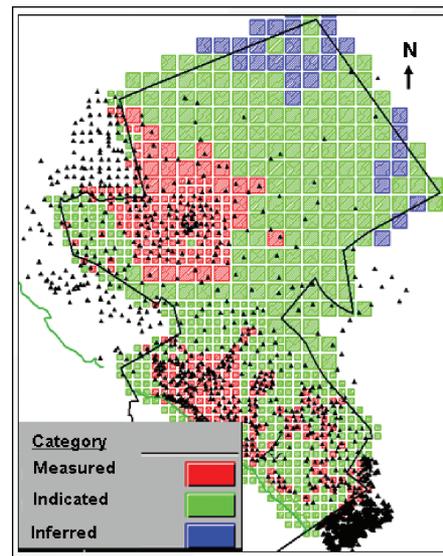


Figure 12. Resource Classification using weighting file

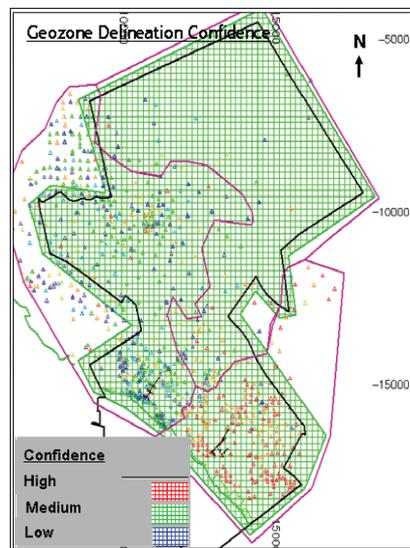


Figure 10. Geozone delineation confidence

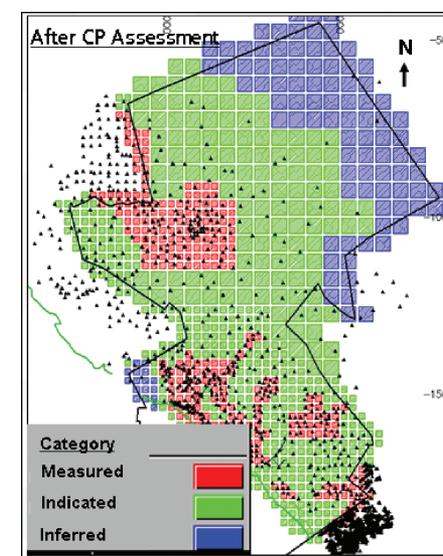


Figure 13. Resource classification after CP's assessment

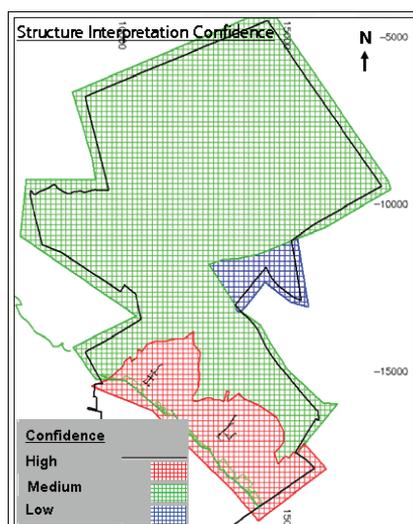


Figure 11. Structure Interpretation confidence

Final classification with CPT sign-off

At the CPT assessment meeting it was deemed appropriate to downgrade some of the model cells for the following reasons:

- A number of blocks were downgraded from indicated to inferred due to the known intrusive iron replacement pegmatoid positions from the aeromagnetic survey as well as their extents on the Merensky Reef.
- Some blocks within and down dip of the Caldera fault were downgraded to inferred.

The final signed off resource classification is shown in Figure 14. The reasons for all reassessments are documented in the CPT report.

Conclusion

The scorecard approach to the classification of mineral resources ensures compliance and provides assurance that the CP has taken due consideration of all pertinent factors when assigning a resource classification. The approach

Table I
Weighting File used

Element Type	Description	Element	Weight %
Statistical	Accumulation	Search volume	6.7%
Statistical	Accumulation	No. of samples	6.7%
Statistical	Accumulation	Kriging efficiency	26.7%
Statistical	Accumulation	Kriging variance	4.4%
Statistical	Accumulation	Regression slope	8.9%
Statistical	Width	Search volume	2.2%
Statistical	Width	No. of samples	2.2%
Statistical	Width	Kriging efficiency	8.9%
Statistical	Width	Kriging variance	2.2%
Statistical	Width	Regression slope	6.7%
Non Statistical	Geological	Aeromagnetics	2.2%
Non Statistical	Geological	Seismics	4.4%
Non Statistical	Geological	Structure	4.4%
Non Statistical	Geological	Geozone/Domains	2.2%
Non Statistical	Geological	Mining history	4.4%
Non Statistical	Geological	Geological loss	4.4%
Non Statistical	Geological	QAQC reports	2.4%
Total Weight %			100.0%

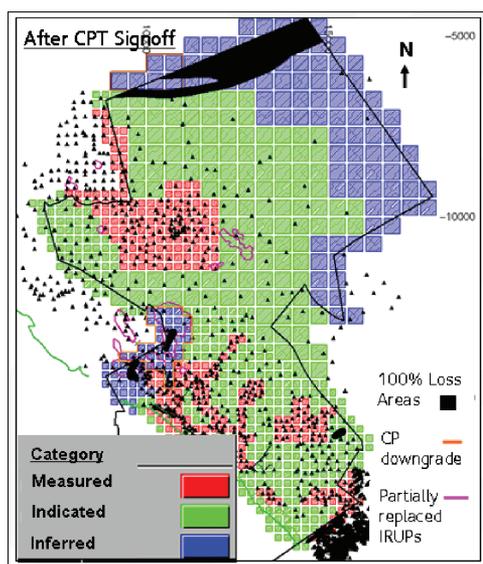


Figure 14. Final resource classification after CPT sign-off

improves the understanding of the relationship between geostatistical and non-geostatistical elements of an orebody and their relationship to the resource classification. It also focuses attention on elements whose confidence can be upgraded to benefit the classification.

In summary, the procedure:

- Integrates risk assessment in the classification
- Integrates input from the geological department and geosciences as a whole
- Develops logical threads between elements
- Enables the classification to be defensible
- Is expandable—the elements being considered can be merged or expanded as understanding develops.
- Is transparent—the spatial distribution of element confidence and weightings are visible
- Is reproducible—given the elements and weighting files
- Provides an audit trail—the CPT report clearly defines how the classification was generated for subsequent model evaluations and external review purposes
- Enables the sensitivity of the classification to the elements and weightings to be visually assessed.



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Started as a bursary holder with Anglo Platinum Limited in 1997 and been employed by the company for the past 10 years. Commenced work at Mogalakwena as a Trainee Geologist in 1999, then appointed at Rustenburg Section as Mine Geologist in 2000. Moved to Head Office in 2004 and is currently employed as a Resource Geologist as part of Paul's team in the Mineral Resources Department.



Paul Stevenson

Principal Geologist, Evaluation, Anglo Platinum Limited

Commenced working at Western Areas gold mine after qualifying with a Geology degree at the University of the Witwatersrand. On returning from a sailing trip to the Caribbean, studied computer programming and joined Shell to develop a computerised geological modelling and mine planning system for coal applications. In 1982 rejoined JCI to implement grade evaluation systems on a mainframe. Powerful geological modelling systems were installed on personal computers throughout the Group's Coal, Base metals, Gold and Platinum divisions in the late 1980's. Paul managed the software support and integration of the geology models with Survey and Mine

Planning systems. Paul now manages a team at Anglo Platinum Limited responsible for the evaluation and reporting of the Groups resources.

