

## Mapping the subsurface for mineral exploration

**Increasing integration of exploration software including 3D data with broad-based GIS systems promises to improve discovery success rates and decision making, according to Louis Racic and Tim Millis of Geosoft.**

The mapping of the Earth's subsurface is critical to understanding our capabilities and limitations with regard to mineral exploration, oil and gas resources, and environmental management. But until recently, visualizing beneath the Earth's surface within GIS has been a complex technical challenge.

There is the data challenge. Mining exploration companies work with huge quantities of geological, geochemical, and geophysical data. Expert handling and visualizing of these multiple data sets and maps has typically required specialized, standalone software.

And there is the efficiency challenge. Exploration is a moving target. Geoscientists are increasingly called upon to edit and refresh subsurface information based on new data, and to combine datasets collected in a variety of formats, such as geophysics, geochemistry, and geology. However, in recent years we've seen increasing integration of exploration software with broad-based GIS systems. New methodologies for the way you can view and interpret subsurface data in the GIS environment have simplified and added new capabilities for the managing of drillhole, borehole, or monitoring well data sets, allowing processing of this data within GIS, as well as presenting the data in a meaningful and appropriate fashion.

Today's GIS subsurface visualization tools allow geoscientists to present data normally visualized on a map, or a set of separate maps, in an integrated fashion, as well as handle and process 'surface' data. Add to that, the ability to display drillhole, borehole, and other subsurface data in 2D and in 3D. Users can manipulate a huge volume of surface and subsurface geochemistry, geophysics, and geology data in 3D within a single or transparently-linked interactive environment. They can augment the drilling results or the environment where the data was collected. And they can plot geochemical surface data and query geological mapping regions.

Armed with these tools, geologists can integrate all available data at every stage of an exploration program to gain a better understanding of the underlying subsurface geology, verify their assumptions, and share their ideas with others on their exploration teams.

### Subsurface viewing: latest generation

It is now possible to display subsurface drilling data within your GIS at any stage in the exploration process - from a few

drillholes at the early stage of an exploration programme, right through to thousands of drillholes during the advanced stages of exploration drilling. The addition of 3D visualization to the traditional 2D has enabled the display of subsurface drillholes and ores in plans, sections, and grids as well as 3D grids within GIS.

There will always be an important place for projecting data in vertical sections onto a plane. But because geologists tend to think in 3D, the additional capability to interactively visualize subsurface data in three dimensions enables them to more easily verify their assumptions. They can put all the interrelationships between the geological model, the geophysical inversions, and the drill hole on the screen, where it can be viewed and shared with investors, managers, safety inspectors, engineers, and other interested parties. 3D subsurface visualization allows users to see the data correctly positioned in its true space, and quickly share interpretations of even complicated structures within the subsurface exploration area.

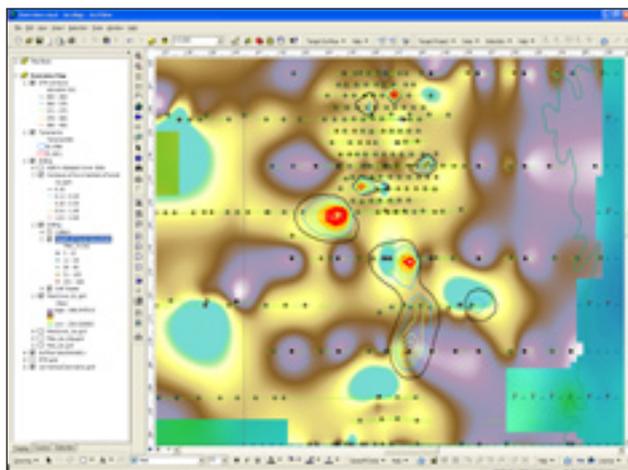
This is valuable at each stage of an exploration programme. In initial reconnaissance of an area, satellite images or geology layers may be draped overtop of a digital elevation model. As projects progress, surface data and potential drill collars are added to the 3D view. Drill traces may be displayed intersecting sections from geophysical inversions to determine if a selected drill target was intersected. In more advanced projects, mineral horizons or sedimentary units are easily displayed as layers within the 3D view. Additionally, geoscientists can create simple representations of complicated downhole 3D data, which they can share with investors, managers, and geologists in deciding where to put the next hole so they can deliver results and plan for the future.

Presented here are a few industry examples that demonstrate how surface and subsurface data from different geoscience disciplines can be processed, visualized, and presented within the ArcMap environment.

### GIS for mining exploration

Geoscientists can deploy GIS in mining and exploration to present data in an integrated fashion by using traditional cross-sections and graphical strip logs, in conjunction with plan map views. This first case study illustrates how data commonly used in mining and exploration can be presented in an integrated fashion within ArcGIS, using traditional cross-sections and graphical strip logs, in conjunction with plan map views.

## Mining Geoscience



**Figure 1** Both the gold grade (ppm) and topographic surface (elevation) for the deepest record of cover sequence (coded as Ca) in each drill hole over the deposit area has been generated, after querying the lithology output shape file for the maximum depth of cover and then joining this to the assay output shape file to select the gold grade associated with the same down-hole.

The study area is on an exploration lease and covers a potential gold deposit located within the Archaean Yilgarn greenstone belt of Western Australia which hosts world-class gold and nickel deposits. Presented on a local coordinate system, data includes surface geochemistry (soil and shallow auger samples), detailed airborne magnetic geophysics, 10 m resolution DTM (digital terrain model), preliminary pit design in a raster format, as well as over 300 drill holes with over 50,000 down hole assay results and geological observations.

In this first example, we examine how to process and present these datasets in the traditional GIS method of a plan view, while ensuring that the data is located, processed, and integrated correctly. Traditionally, most geoscientists' when looking at large regional datasets want to determine the best grade within a drill hole, or the end of hole grade.

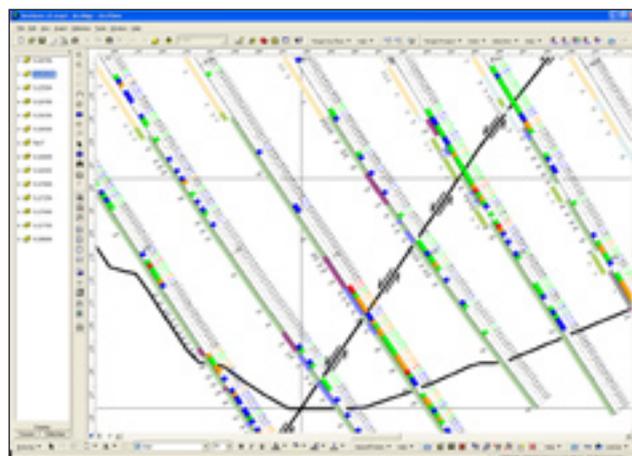
One option is to use drillhole mapping functionality within GIS to output the data in shape file format in its correct down hole locations. Geoscientists can then query these shape files to determine best grade within a geological sequence, average mean grade within a particular elevation slice, or even the topography of a horizon (such as maximum depth of cover sequences). By calculating and storing the true X, Y, and Z location for all from-to or discrete point depth intervals based on collar location (east-ing, northing, and elevation) and any down hole survey information (usually collected as a dip and azimuth at a particular depth down hole), one can write out this data to the shape file(s). Then, when these points are plotted onto a map, the location of the point is the correct location in

space, when projected back to surface. This means a more accurate and precise determination of where mineralization, geology, regolith, etc is in relation to other surface and sub-surface data. From these selections, data can be gridded and contoured to represent the data points as surfaces. Figure 1 illustrates the results.

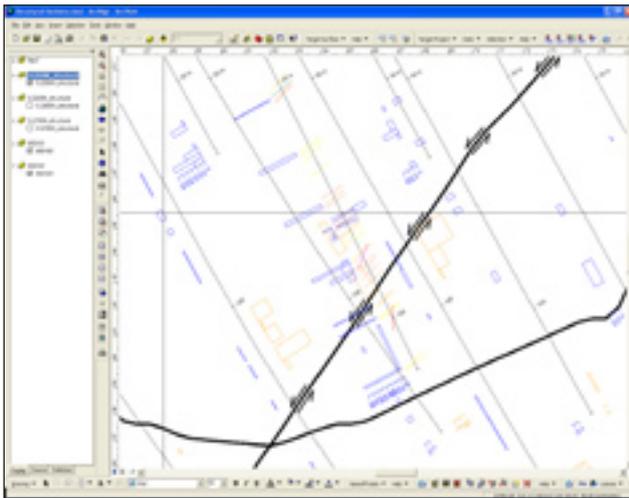
In this particular example, both the gold grade (ppm) and topographic surface (elevation) for the deepest record of cover sequence (coded as Ca) in each drill hole over the deposit area has been generated, after querying the lithology output shape file for the maximum depth of cover and then joining this to the assay output shape file to select the gold grade associated with the same down-hole interval.

The next example details one of the more important aspects of visualizing drillhole data: cross sections in the vertical plane of the drilling. Having the ability to generate these within the GIS environment is a significant advancement within ArcGIS. Geoscientists can now generate sections within the GIS environment along east-west, north-south, or even oblique angles across an area. Down hole data can be presented in a variety of ways, including bar plots (histograms) and profiles; numeric bands, posted values, or even 'gridded' using different processing algorithms coloured by unique, user-definable cut-offs; posted text or as patterns determined by a text code; and even structural measurements showing the apparent dip of a structure relative to the plane of the section.

Figures 2 and 3 demonstrate a number of these plot types. Figure 2 displays lithology plotted with regolith as text and patterned bands, gold results in ppm (parts per million) as coloured numeric bands and the actual result as a coloured value. Figure 3 illustrates how structure-related data can be presented as bar plots (vein and sulphide content percentages) and colour-coded lines or 'ticks' (apparent dip on section from the dip and dip direction measured of a structure).



**Figure 2** This displays lithology plotted with regolith as text and patterned bands, gold results in ppm (parts per million) as coloured numeric bands and the actual result as a coloured value.



**Figure 3** Structure-related data can be presented as bar plots (vein and sulphide content percentages) and colour-coded lines or ‘ticks’ (apparent dip on section from the dip and dip direction measured of a structure)

Integrating other data sets with the drilling data to ascertain as much information as possible is also possible: one can plot the original topographic surface, pit design and a major fault plane (also showing sense of movement) with the sectional information, and all three can be derived from where the section plane intersects digital terrain models (DTM) for each of the datasets. Presenting the data in the manner illustrated in Figure 4 allows for determining how other data sets relate to the subsurface results. In this case, the observation of a slight geochemical signature over the deposit area, even though there is up to 50 m of transported cover sequences, has implications for using surface geochemical sampling to detect other ‘buried’ deposits within the tenement area and beyond. The interpreted fault plane can be seen to coincide with a change in the gradient of the magnetics, hence giving the explorationist an indication that structural control on mineralization is coincident with linear magnetic anomalies.

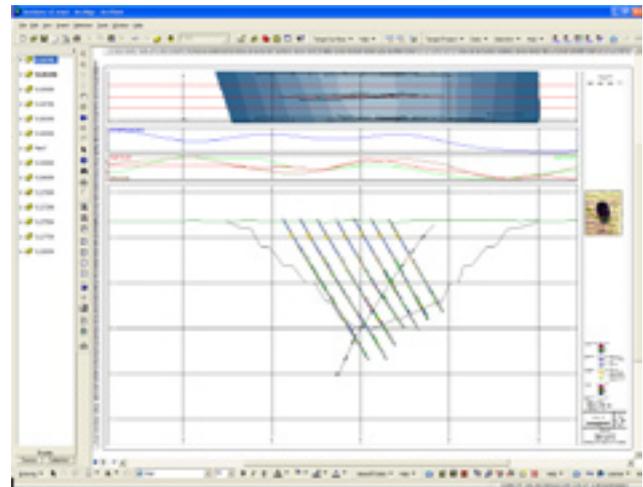
In the same ‘integration’ theme, one can display multiple data frames on the final map layout to present different plotting styles, thereby providing more detailed presentations of data. In Figure 5, along with presenting structural data in a cross-sectional view so the overall relationships can be visualized, more detailed graphic strip logs for two diamond drill holes are also included. Each of these strip logs (drill holes SKD433 and SKD434) are plotted for the intervals of interest (where the structural data is the most detailed) rather than for holes in their entirety.

In Figure 6, the lithological data on each log is plotted as a coded pattern, with vein percent as a bar plot. Structural data was collected as ‘alpha’ and ‘beta’ readings, ie dip and dip direction of the structure relative to the axis of the drill

core and then orientated to the true dip and dip direction based on the dip and azimuth of the drill hole at the point of the structure. There is a fracture density ‘rose’ diagram, a ‘tadpole’ plot, where the head of the tadpole represents the dip of the structure (0-90° on the graph), and the tail the direction of the dip (relative to north, which is up the page) and two stereographic representations of the structures, with the left-hand side plotting the pole to plane of the structure on an equal-area ‘Schmidt’ diagram and the right-hand side diagram the dip and dip direction plotted on a polar projection.

Both the tadpole plot and stereonets are colour-coded according to the type of structure plotted (fold and metamorphic fabrics, fault, fracture, and joint sets and other bedding features) that were recorded along with the orientation of the structure. The fracture density and stereonets are plotting data based on 10 m intervals within the sequence selected to plot.

Combining these strip logs on the actual cross section makes interpreting the trends in structure much less arduous, and also keeps datasets ‘together’. Interpreting these readings gives an indication that most of the structure and fabric within the rocks themselves dips to the west through to west-southwest at an angle of 45-70° to the horizontal. This also coincides with the average dip and dip direction of the mineralization in the deposit, reinforcing that there are strong structural controls on the orientation of the mineralization, even though much of the gold is not associated with quartz veining.



**Figure 4** A set of windows which display the profile line of where the section plane again intersects gridded gold in soils (red line) and gold (brown) and arsenic (green) from shallow auger sampling over the drilling area with the profile for the 1st vertical derivative magnetics (blue) in a separate window; and in plan view, the section location and width of section window along with the traces of the drill holes projected to surface with the DTM of the pit design as a backdrop, coloured by the bench elevations

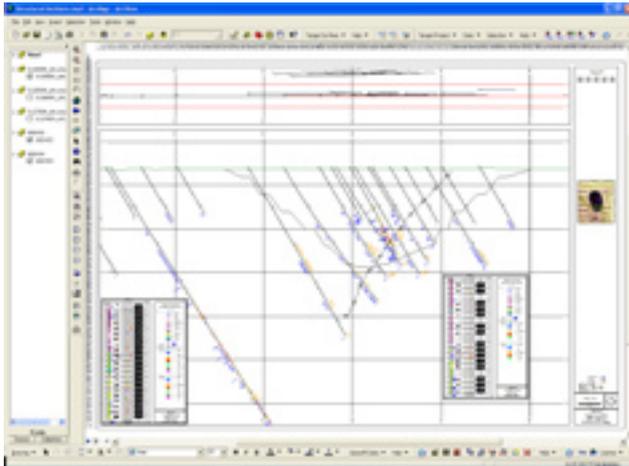


Figure 5

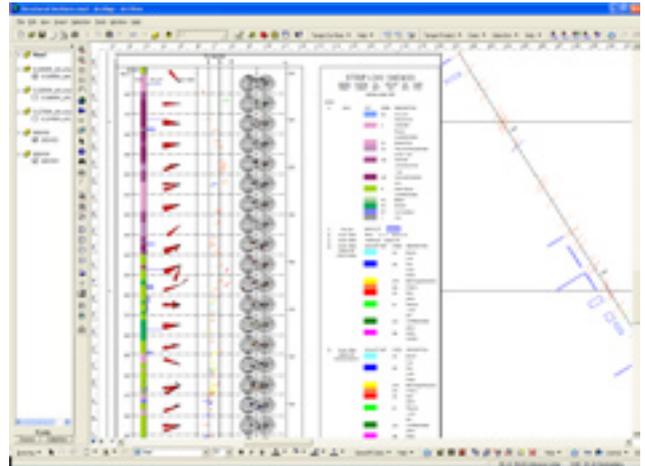


Figure 6

Another possibility is to use a subsurface 3D view in GIS to visualize a proposed pit design, as is illustrated in Figure 7. This image can be rotated so the user can view the pit design from every angle. This is useful in near-mine exploration efforts to stay aware of the progress of the open pit and potentially extend the existing ore zones in the mine. Being able to see what is happening in the exploration area around the mine as well as in the mine allows mine geologists and exploration geologists to integrate their efforts.

**Environmental management**

The functionality of GIS for mapping the plants, soils, and water of a region is making it an invaluable tool for mines to process and present the environmental impact that may be caused by mining activities, as well as reclamation efforts. Many use GIS to analyze what is happening at monitoring wells and subsurface sampling alongside other important information, such as groundwater levels and geological strata controls.

It is particularly valuable to monitor temporal changes in monitoring wells. Users can take a ‘snapshot’ of the data at a

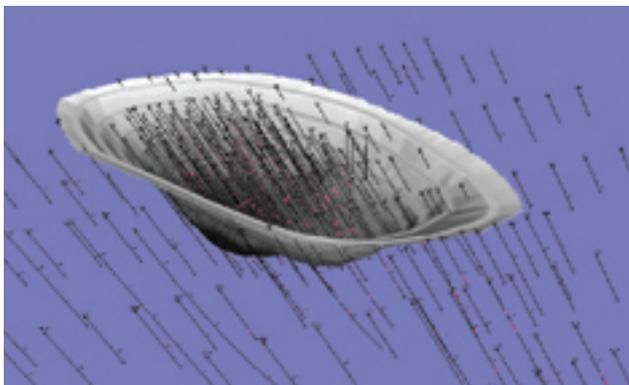


Figure 7 These drillholes show gold values as histograms along the hole, in a proposed pit design.

point in time every day, week, or month, and eventually play that data, like a movie, to graphically show changes - or no changes - over time.

Using geological information and benzene and toluene results from monitoring wells placed to observe oil seepage from a pipeline rupture through to groundwater as well as waterflow information, for instance, users can determine the elevation at which contamination is greatest, the direction of flow of an oil plume, the level of benzene and toluene contamination within the substrate, water table at different levels, and also how stratigraphy is influencing the direction and dispersal of the oil in the strata and ground water.

With such information available in an integrated manner, an environmental monitoring team can determine where extra well locations may be needed to continue to examine the downstream flow of contamination within the water table, as well as base-line figures for monitoring future results, all of which they can amalgamate back onto the original map, or onto a new series of maps published in the same format.

**Oil spill contamination**

This final example examines how environmental impact and monitoring studies using well monitoring and subsurface sampling can be processed and presented with other information, such as groundwater levels and geological strata controls. The data in the study is theoretical, but is based on real-world examples of where oil seepage from a pipeline rupture through to groundwater is observed with a series of monitoring wells.

The way data from the monitoring wells (geological information and benzene and toluene results) is presented is in plan ‘slices’ at particular elevations, as well as an oblique long section through the theoretical oil plume itself, with benzene and toluene results gridded using the minimum curvature algorithm to determine the distribution of the contamination both in plan and section view.

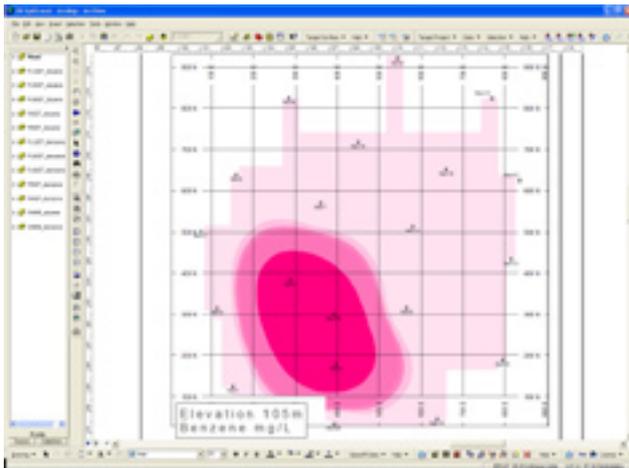


Figure 8

Figure 8 illustrates the elevation at which contamination is greatest and the direction of flow of the oil plume itself. Each horizontal slice is generated at 5 m intervals from the 110 m RL (Relative Level of true elevation) which is approximately 5 m below the collar position of the closest down-slope monitoring well to the point of rupture (well number Mon19). The gridded benzene and toluene (measured in mg/L) results are generated by nominating the thickness of the slice (in this case 5 m, which equates to  $\pm 2.5$  m above and below the plane of the reference elevation); the assay intervals (1 m) that fall within that slice window are composited on a weighted mean average basis, projected back to the plane of the elevation, then the minimum curvature algorithm is applied.

To generate the benzene and toluene elevation slices, the data plotting parameters can be changed, and the plots regenerated at the set intervals. The same classified colour schema on each plot variable (i.e. benzene or toluene) as a parameter within the data plotting routine means that all resultant grids display with the same colour stretch automatically.

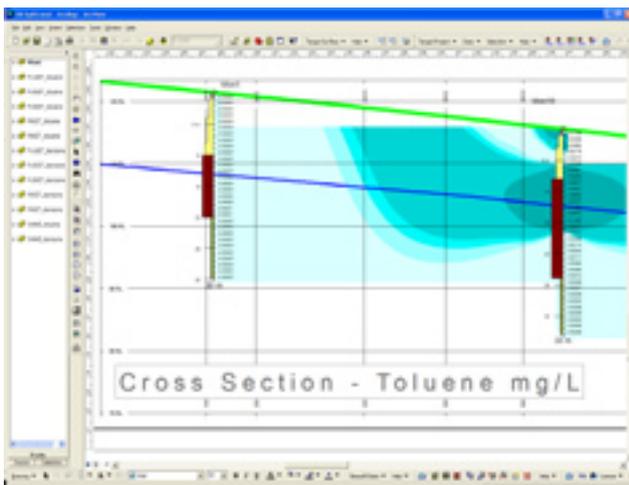


Figure 10

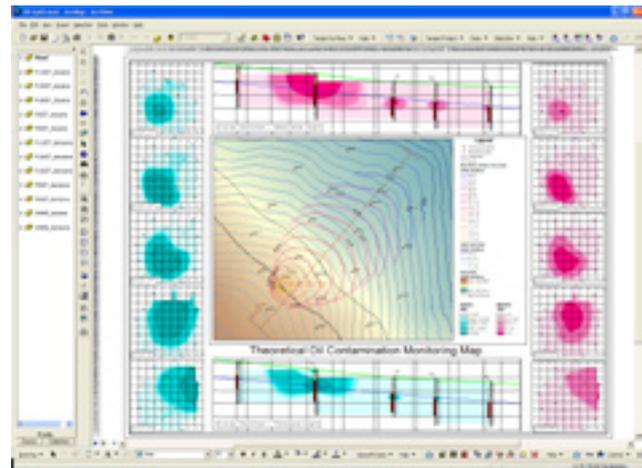


Figure 9 visualizes the data if water flow information was also collected. (The actual location of the section is oblique to the local coordinate grid of the monitoring well stations.) Users can choose to process and present this data in the same way as above, or integrate it into each elevation plan view as contours, such as the ground water level in the main plan or the theoretical oil plume gradient.

Combining all the data in this way allows an observer to determine the sense of flow of the underground oil plume in both the horizontal (plan) and vertical (section) planes, the level of benzene and toluene contamination within the substrate and water table at different levels, and also how stratigraphy is influencing the direction and dispersal of the oil in the strata and ground water.

There are limitations to this way of presenting the data. Because the real depth to water table and depth of the drilling is quite shallow within the section views, generating a cross section view at 1:1 scale over such an area would result in much of the detail being lost. Geoscientists have developed ways of addressing this concern. Figure 10 illustrates how a long section generated with a vertical exaggeration of 1:5 allows presentation of the data at a scale that is visible, and still meaningful. In both sections, the actual chemical analysis result is plotted down hole for benzene and toluene (respectively) as well as gridded by applying a minimum curvature algorithm, with the geological data in section also presented with average grain size as a profile line down-hole, colour-filled according to geological observations (the three main rock types observed in this data set are silt, sand, and gravel in this area, with a gradation in material from fine silt through to coarsening sands to coarse gravel, back to a fine silt base).

In section, a representation of both the surface topography and water table datasets has been drawn onto the section automatically, the lines in the section defined by where the centre of the section passes through the surface and water table grids, reading the 'z' attribute of the cells intersected by the plane of the section.

## Mining Geoscience

### Summary

Mining geologists and near mine exploration geologists alike can use GIS to create, access, display, and analyze subsurface geoscience data sets, such as geophysical grids, geochemical assays, and geological features. They can use it to display subsurface drillhole data in level plans, sections, drill logs and 3D – an important addition to their ability to use GIS to grid

or contour surface or subsurface datasets, import geophysical images, plot and attribute geochemical data, query geological mapping regions, and map claim boundaries.

The numerous capabilities in integrating, presenting, and analyzing surface and subsurface data - in 2D and in 3D - within a GIS environment will continue to result in more focused and efficient exploration efforts as well as better decisions.



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