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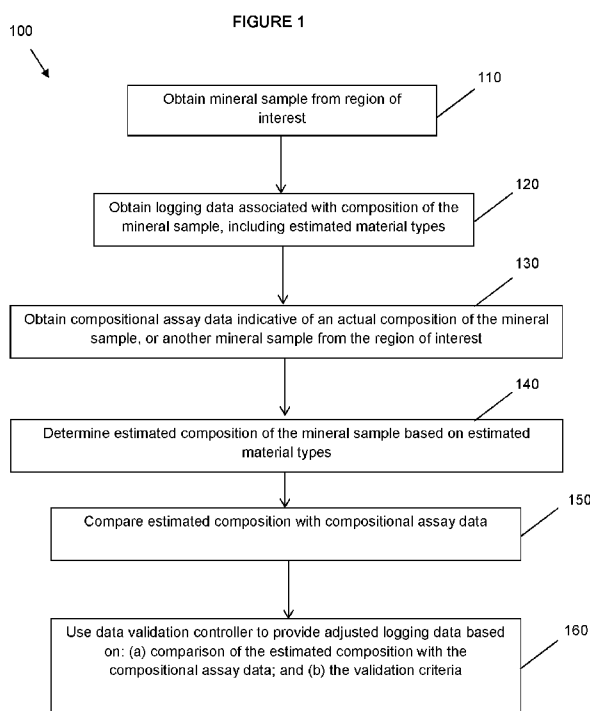
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(54) Title: A METHOD AND SYSTEM FOR VALIDATING LOGGING DATA FOR A MINERAL SAMPLE



(57) Abstract: Disclosed is a method for validating logging data for a mineral sample which has been obtained from a region of interest. The method comprises obtaining logging data associated with a composition of the mineral sample, the logging data including one or more estimated material types present in the mineral sample. Compositional assay data indicative of an actual composition of the mineral sample or another mineral sample provided from the region of interest, is obtained. An estimated composition of the mineral sample is then determined based on the estimated material types. The estimated composition is then compared with the compositional assay data, and a data validation controller is used to provide adjusted logging data based on: the comparison of the estimated composition with the compositional assay data; and stored validation criteria which defines allowable modifications to the estimated material types based on physical properties associated with the material types.

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## A METHOD AND SYSTEM FOR VALIDATING LOGGING DATA FOR A MINERAL SAMPLE

### Field of the Invention

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The present invention relates to a method and system for validating logging data for a mineral sample, such as but not limited to drill-hole logging data.

### Background

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Mining explorations typically involve obtaining mineral samples from a drill site and evaluating the composition of those samples to determine whether a resource is present at the site. One technique for obtaining mineral samples is reverse circulation (RC) drilling, where drill cuttings or chips are brought to the surface by a circulation of air through the drill. Samples of drill chips are typically collected for regular depth intervals during drilling (e.g. 2 metre intervals) to evaluate the mineral composition throughout a length of the drill-hole.

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For each interval, a sample of drill chips may be logged and another sample may be sent to a laboratory for compositional assay, for example by X-ray fluorescent (XRF) analysis. Field logging of drill-hole samples involves visually inspecting the samples and recording the material types present as well as other physical characteristics such as colour, shape and texture.

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Field logging is a routine practice typically done by geologists. While compositional assay can reveal the elemental composition of a sample, field logging is necessary to determine geological material types present in a sample, such as hematite, goethite, shale etc. Information regarding both the composition and material type of drill samples is necessary to better understand the structures and mineralogical compositions of an area. Such information can then be used for ore-body modelling and the development of mining plans.

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The accuracy of the field logging data is therefore important for resource evaluation and planning in the minerals industry. However, inaccuracies in the material types logged may arise not only due to diversities in mineralisation and geology, but also due to subjective biases and human error. There may also be inconsistencies between the

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validations performed by different geologists. It is therefore common for the estimated composition of the logged chips to differ from the actual composition, and thus validation of the logging data is required to check and/or improve its accuracy.

- 5 For iron ore exploration and mining in particular, incorrect drill-hole logging information can result in outcomes with significant financial implications. For example, material types such as ochreous goethite and shale are commonly confused due to similarities in colour and texture in chip samples obtained from RC drilling. However, chemically these material types are very different; for instance, shale (kaolinite) is high in silica  
10 and alumina and low in iron, whereas ochreous goethite has a high iron grade but is much lower in silica and alumina than shale. Furthermore, ochreous goethite tends to be sticky due to its water holding capacity, which can cause problems such as blocking screen decks and ore transfer chutes, leading to unplanned downtime. Validation during iron ore exploration can thus provide more accurate knowledge of the  
15 distribution of ochreous goethite, which can assist in planning blending strategies to manage risks in mining.

Validation is also an extremely time consuming and labour-intensive task and there may be hundreds of kilometres of RC drill-holes drilled each year.

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#### Summary of the Invention

According to a first aspect of the present invention, there is provided a method of validating logging data for a mineral sample obtained from a region of interest, the  
25 method comprising:

obtaining logging data associated with a composition of the mineral sample, the logging data including one or more estimated material types present in the mineral sample;

- 30 obtaining compositional assay data indicative of an actual composition of the mineral sample or another mineral sample provided from the region of interest;

determining an estimated composition of the mineral sample based on the estimated material types;

- 35 storing validation criteria in a data storage, the validation criteria defining allowable modifications to the estimated material types based on physical properties associated with the material types;

comparing the estimated composition with the compositional assay data; and

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using a data validation controller to provide adjusted logging data based on: the comparison of the estimated composition with the compositional assay data; and the validation criteria.

- 5 By adjusting the logging data using a data validation controller, the overall validation process can be made more efficient compared to the manual validation process described above. Moreover, since the adjustment by the data validation controller is guided by stored validation criteria, improved consistency in the validation of various logging data may be achieved.

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Further, a better understanding of geological properties of the region of interest can be gained not only by determining the actual composition of a sample from the region of interest, but also by examining the material types logged for a sample from the same region of interest. Modifying the estimated material types, for example by reducing a difference between the estimated composition of the material types logged and the actual composition, may improve the accuracy of the material type originally logged while maintaining important information concerning the types of materials present at the region of interest.

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- 20 The logging data may comprise an estimated proportion of each material type in the mineral sample.

The logging data may further include at least one physical property of the mineral sample associated with the logging data.

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The validation criteria may comprise information indicative of material type substitution rules defining allowable material type substitutions according to which the logging data can be adjusted.

- 30 The method may further comprise using the data validation controller to adjust the logging data by substituting at least a portion of at least one material type in the logging data for at least one other material type according to one or more applicable material type substitution rules.

- 35 Prior to substituting at least a portion of the at least one material type, the method may comprise selecting one or more of the applicable material type substitution rules by

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determining a component of the estimated composition that satisfies a predefined condition.

5 Determining the component of the estimated composition that satisfies the predefined condition may comprise determining the component of the estimated composition that has a greatest degree of difference from a corresponding component of the composition assay data.

10 By substituting material types according to substitution criteria, geologically invalid material type substitutions may be prevented. For example, an allowable material type substitution would not exist for a case where a particular material type would never be substituted for another material type.

15 Adjusting the logging data may produce one or more corresponding intermediate states of the logging data, the intermediate states having a theoretical composition and at least one theoretical physical property.

20 The method may comprise defining error tolerance values for one or more of: at least one component of the estimated composition; a hardness of the mineral sample; and a lump percentage indicative of a proportion of particles in the mineral sample that is greater than a particular size.

25 Adjusting the logging data may comprise adjusting the estimated proportions of the material types or corresponding intermediate states without exceeding one or more of the error tolerance values.

30 The method may comprise adjusting the one or more corresponding intermediate states while minimising a degree of difference associated with the at least one physical property of the logging data and the at least one physical property of the theoretical composition.

35 The method may comprise associating each corresponding intermediate state with a penalty value and ranking the one or more corresponding intermediate states according to the penalty value, wherein the penalty value is determined based on one or more of the following:

- 5 -

a presence of incompatible material types in the one or more corresponding intermediate states;

a particular material type in the logging data being inconsistent with a geological context of the region of interest; and

5 a distinctive material type originally present in the logging data being removed, or a distinctive material type originally absent from the logging data being added, as a result of the processor adjusting the logging data.

The method may comprise selecting a predetermined number of the intermediate  
10 states according to ranking.

The method may comprise repeating the method from the step of adjusting the logging data with the estimated composition being replaced with the selected intermediate states, in order to generate a plurality of penultimate states of the logging data.

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The method may comprise associating each penultimate state with a final penalty value and ranking the plurality of penultimate states according to the final penalty value, wherein the final penalty value is based on one or more of the following:

20 at least one physical property of the logging data and at least one physical property of the theoretical composition;

a total amount of material type substitutions experienced by each penultimate state; and

a presence of incompatible material types in each penultimate state.

25 According to a second aspect of the present invention, there is provided a system for validating logging data obtained for a mineral sample from a region of interest, the system comprising:

a data input system arranged to receive:

30 user input logging data associated with a composition of the mineral sample, the logging data including one or more estimated material types present within the mineral sample, and;

compositional assay data indicative of an actual composition of the mineral sample, or another mineral sample provided from the region of interest, determined by assaying the or the other mineral sample;

35 the system arranged to determine an estimated composition of the mineral sample based on the estimated material types;

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the system further comprising a data storage storing validation criteria defining allowable modifications to the estimated material types based on physical properties associated with the material types; and

5 a data validation controller arranged to: compare the estimated composition and the compositional assay data, and adjust the logging data based on the comparison and the validation criteria.

The logging data may comprises an estimated proportion of each material type in the mineral sample.

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The logging data may further include at least one physical property of the mineral sample associated with the logging data.

15 The validation criteria may comprise information indicative of material type substitution rules defining allowable material type substitutions according to which the logging data can be adjusted.

20 The controller may be arranged to adjust the logging data by substituting at least a portion of at least one material type in the logging data for at least one other material type according to one or more applicable material type substitution rules.

25 The system may be arranged such that prior to substituting at least a portion of the at least one material type, the system selects one or more of the applicable material type substitution rules by determining a component of the estimated composition that satisfies a predefined condition.

30 The system may be arranged to determine the component of the estimated composition that satisfies a predefined condition by determining the component of the estimated composition that has a greatest degree of difference from a corresponding component of the composition assay data.

35 The controller may be arranged to produce one or more corresponding intermediate states of the logging data as a result of adjusting the logging data, the intermediate states having a theoretical composition and at least one theoretical physical property.

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The controller may be arranged to adjust the estimated proportions of the material types or one or more corresponding intermediate states without exceeding one or more error tolerance values.

- 5     The error tolerance values may be associated with one or more of: at least one component of the estimated composition; a hardness of the mineral sample; and a lump percentage indicative of a proportion of particles in the mineral sample that is greater than a particular size.
- 10    The system may be arranged to modify the one or more corresponding intermediate states while minimising a degree of difference associated with at least one physical property of the logging data and at least one physical property of the theoretical composition.
- 15    The system may be arranged to associate each corresponding intermediate state with a penalty value and rank the one or more corresponding intermediate states according to the penalty value.

20    The system may be arranged to determine the penalty value based on one or more of the following:

- a presence of incompatible material types in the one or more corresponding intermediate states;
- a particular material type in the logging data being inconsistent with a geological context of the region of interest; and
- 25     a distinctive material type originally present in the logging data being removed, or a distinctive material type originally absent from the logging data being added, as a result of the processor adjusting the logging data.

30    The system may be arranged to select a predetermined number of the intermediate states according to ranking.

The system may be arranged to adjust the logging data with the estimated composition being replaced with the selected intermediate states, in order to generate a plurality of penultimate states of the logging data.

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The system may be arranged to associate each selected intermediate state with a final penalty value and rank the plurality of penultimate states according to the final penalty value.

- 5     The final penalty values may be determined based on one or more of the following:  
            at least one physical property of the logging data and at least one physical  
property of the theoretical composition;  
            a total amount of material type substitutions experienced by each penultimate  
state; and  
10    a presence of incompatible material types in each penultimate state.

The system may be arranged to select a predetermined number of the penultimate states with the lowest final penalty value, and present the selected penultimate states to a user.

- 15    The input system may comprise an input device arranged to allow the user to select at least one of the selected penultimate states to for acceptance as a final validated composition.

- 20    According to a third aspect, there is provided a method of validating logging data for a mineral sample, the method comprising:  
            providing the mineral sample from a region of interest;  
            obtaining logging data associated with a composition of the mineral sample;  
            assaying the or another mineral sample provided from the region of interest to  
25    determine the composition of the or the other mineral sample;  
            comparing the composition associated with the logging data with the composition determined by assaying the or another mineral sample; and  
            using a processor to automatically provide adjusted logging data, the adjusted logging data being provided based on a result of the comparison of the composition  
30    associated with the logging data with the composition determined by assaying the or another mineral sample and using at least one predetermined criterion.

According to a fourth aspect, there is provided a method of validating logging data for a mineral sample, the method comprising:

- 35       providing the mineral sample from a region of interest;

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receiving user input logging data associated with a composition of the mineral sample, the composition having at least one component;

receiving an actual composition of the mineral sample, or another mineral sample provided from the region of interest, determined by assaying the or the other mineral sample;

using a processor to automatically: determine a difference between the composition associated with the logging data and the actual composition, and; adjust the logging data to reduce the difference according to at least one predetermined criterion, in order to provide or assist in providing validated logging data.

According to a fifth aspect, there is provided a system for validating logging data obtained for a mineral sample, the system comprising:

a data input system arranged to receive: user input logging data associated with a composition of the mineral sample, the composition having at least one component, and; an actual composition of the mineral sample, or another mineral sample provided from the region of interest, determined by assaying the or the other mineral sample; and

a data validation controller arranged to: determine a difference between the composition associated with the logging data and the actual composition, and; adjust the logging data to reduce the difference according to at least one predetermined criterion, in order to provide or assist in providing validated logging data.

According to a sixth aspect, there is provided a method for validating the composition of a mineral sample comprising the steps of:

receiving user input data comprising observed physical properties and estimated material properties of a mineral sample;

receiving assayed data comprising composition of a mineral sample;

generating a theoretical composition of the sample from the estimated material properties;

calculating a difference between the composition of the mineral sample and the theoretical composition;

automatically adjusting the estimated material properties to reduce the difference and maintain the observed physical properties.

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### Brief Description of Drawings

Figure 1 is a flow diagram of a method according to an embodiment of the present invention.

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Figure 2 is schematic diagram of a system according to an embodiment of the present invention.

Figure 3 is a functional block diagram of a controller of the system shown in Figure 2.

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Figure 4 is a schematic diagram showing components of a storage device of the system shown in Figure 2.

Figure 5 is a flow diagram of a method according to an embodiment of the present invention.

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Figures 6, 7 and 8 show display arrangements displayed on an output device of the system shown in Figure 2 when the system is in use.

20 Figures 9, 10 and 11 are flow diagrams of methods according to embodiments of the present invention.

### Detailed Description

25 Figure 1 is a flowchart of a method of validating logging data for a mineral sample according to an embodiment. The method 100 will herein be described in the context of iron ore mining exploration using reverse circulation (RC) drilling to obtain mineral samples. However, a person skilled in the art will appreciate that the disclosed method can be used in other applications and can involve other drilling techniques.

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Throughout this specification, unless the context requires otherwise due to express language or necessary implication:

- 35 • The term “composition” and variants thereof refer to a chemical composition of a material, i.e. a set of chemical elements, compounds and/or other constituents, such as but not limited to Fe, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, P, S, Mn, MgO, TiO<sub>2</sub>,

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CaO, H<sub>2</sub>O, LOI425 (goethite-bound water) and LOI650 (kaolinite associated water), which might be present in a mineral sample. The term “composition” may also be used in a manner that refers to the amounts or proportions of these chemical elements and/or compounds present in a mineral sample.

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- The term “material type” refers to a type of material based on its mineralogical and/or textural composition. Each material type has specific physical properties such as hardness, texture, colour and shape. Each material type has known theoretical composition. For example, ochreous goethite is a material type that  
10 has high iron (Fe) content, but is relatively low in silica (SiO<sub>2</sub>) and alumina (Al<sub>2</sub>O<sub>3</sub>). Some material types may have very similar chemical compositions, but different physical properties.
- The term “validate” or variants thereof, with respect to data, refer to a process  
15 or action that includes checking the data for accuracy and/or modifying the data to improve its accuracy.

In this example, the mineral sample of concern in the method 100 is obtained from a region of interest (step 110). The region of interest according to a specific embodiment  
20 is at a particular depth or depth range of a drill-hole. Samples of drill cuttings or chips brought to the surface are collected for each regular length intervals of the drill-hole. For example, if the intervals are chosen to be 2 metre intervals, drill chips may be collected for each of the ranges 18m-20m, 20m-22m, 22m-24m etc. below the surface.

25 The method further comprises obtaining logging data associated with a composition of the mineral sample (step 120). The logging data includes one or more estimated material types present within the mineral sample, which will be described in more detail below. The method also comprises obtaining compositional assay data indicative of an actual composition of the or another mineral sample provided from the region of  
30 interest (step 130). According to a specific embodiment, the mineral sample in step 130 is a different sample to the mineral sample referred to in step 120, but the samples are obtained from the same region of interest (e.g. 2 metre drilling interval).

To provide context, in one example, once drill chips for a particular drilling interval are  
35 brought to the surface, a rotary cone splitter may be used to divide the drill chips into two portions of substantially equal distribution, thus providing the two samples. Of

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those equally proportioned samples, one sample is logged (e.g. by a geologist) and another sample is sent to be analysed or assayed (e.g. in a laboratory) to determine its actual elemental composition. In another example, the mineral sample in step 130 may be obtained from sampling a drill hole chip cone formed by blast hole drilling without the use of a rotary cone splitter. The sample to be logged may be obtained by selecting a cross-section of the cone of drill hole chips and the sample to be analysed or assayed obtained similarly. In this example, the cone cross-section represents material from the entire drill hole, wherein the drill hole is represented by a single interval. A hole drilled using this method may or may not have a skirt placed around the drill to contain the chips.

For ease of reference, the sample that has been logged will be referred to as the “logged sample”, and the sample that has been assayed will be referred to as the “assayed sample”. It will be appreciated that because the logged sample and the assayed sample are obtained from the same region of interest, they are expected to have similar compositions.

In step 120, the logging data in this example comprises information regarding the logged sample obtained from field logging. Such field logging includes visual inspection of the samples to estimate the percentages of various material types present. The logging data may include estimates of various material types in the sample in increments of between 1% and 10%, such as 5%. Material types may be identified at scales ranging from microscopic to macroscopic. These qualitative physical properties may remain consistent across various sites, though minor changes in geochemistry may occur.

Some material types that have been defined for iron ore explorations are provided in Table 1 table below.

TABLE 1: Examples of Material Types defined for use during Iron Ore Explorations

| Class                        | Material Type                           | Code |
|------------------------------|-----------------------------------------|------|
| Goethite dominant mineralogy | Vitreous/ochreous goethite              | GOE  |
|                              | Ochreous goethite                       | GOL  |
|                              | Vitreous goethite                       | GOV  |
| Hematite                     | Microplaty hematite + martite (friable) | H2F  |

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|                              |                                                                    |     |
|------------------------------|--------------------------------------------------------------------|-----|
| goethite mineralogy          | Microplaty hematite + martite (hard)                               | H2H |
|                              | Microplaty hematite + martite (medium)                             | H2M |
| Hematite dominant mineralogy | Martite-ochreous goethite $\pm$ vitreous goethite                  | HGF |
|                              | Martite $\pm$ microplaty hematite $\pm$ vitreous/ochreous goethite | HGM |
|                              | Martite-vitreous goethite $\pm$ ochreous goethite                  | HGH |
| Selected waste               | Shale                                                              | SHL |
|                              | Siderite                                                           | SID |
|                              | Banded iron formation (waste)                                      | BIF |
|                              | Calcrete                                                           | CAL |
|                              | Chert                                                              | CHT |
|                              | Clay                                                               | GLA |

In addition to recording an estimate of material types present, the geologist may also record an estimate of other physical characteristics of the logged sample. For example, such as the sample colour, chip shape, hardness, texture, and magnetic susceptibility  
5 can also be observed and noted during field logging.

In step 130, compositional assay data is obtained, the data being indicative of an actual composition of the mineral sample or another mineral sample from the region of interest. In this example, the compositional assay data is obtained by assaying a  
10 sample from the same drilling interval as the logged sample. More specifically, the assay utilises X-ray fluorescent (XRF) analysis to determine the actual composition, and amounts of those components, of the assayed sample. In this particular example, the XRF analysis determines the amount of Fe, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, P, S, Mn, MgO, TiO<sub>2</sub>, CaO, Total LOI, LOI425 (measuring goethite-bound water) and LOI650 (kaolinite associated  
15 water) content. It will be appreciated that other analytical techniques can be used.

The method 100 also comprises determining an estimated composition of the mineral sample (step 140), and thus also of the drilling interval associated with the logged sample, based on the percentage of the estimated material types logged and the  
20 theoretical composition of the material type.

Thus, after steps 120, 130 and 140, an estimated composition of the logged sample and an actual composition of the assayed sample have been obtained.

25 These estimated and actual compositions are then compared for the purpose of validating the estimated composition (step 150). This validation is required because

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field logging is subject to geological and mineralogical diversities as well as human error. The field logging data nevertheless remains an important source of information regarding the physical characteristics of the sample that cannot be obtained by laboratory analysis, which is important for resource evaluation and planning in the minerals industry.

Step 160 of the method comprises using a data validation controller to provide adjusted logging data based on: (a) a result of the comparison from step 150; and (b) validation criteria. As will be described in more detail below, the validation criteria defines allowable modifications to the estimated material types based on physical properties associated with the material types, and are stored in data storage accessible by the data validation controller. The data validation controller may comprise any device capable of processing program instructions typically stored as program code in a data storage device, such as a processor, microprocessor, microcontroller, programmable logic device, a computing device, or any other suitable processing device.

In that regard, according to an embodiment, the steps 140 to 160 of the method 100 are performed using a data validation system 200 for validating logging data obtained for a mineral sample. With reference to Figure 2, the system 200 comprises a data input system 210 arranged to receive logging data associated with the logged sample and compositional assay data indicative of an actual composition of the or another mineral sample from the region of interest, obtained from analysis of the assayed sample. The system 200 further comprises a data validation controller 220 arranged to compare the estimated composition and the compositional assay data, and adjust the logging data based on the comparison and the validation criteria.

In this example, the data validation controller 220 includes a processor 222 and data storage 224 in which program instructions are stored to be executed by the processor 222. Therefore, the data validation controller 220 in this embodiment can perform steps 140 to 160 of the method 100 described above. Accordingly, for convenience, other method steps in further embodiments of the invention will be discussed in the context of implementation by the validation system 200.

**System Operation**

- In this embodiment, the validation system 200 also comprises an output device 240 for the controller 220 to allow a user to interact with the system 200. In particular, the
- 5 output device 240 displays at least an outcome such as the adjusted the logging data after the controller has processed the data according to at least one predetermined criteria. The output device 240 may be for example a graphical user interface a computing device (see Figures 6 and 7).
- 10 The output device 240 in this embodiment also displays information indicative of input data. In this regard, the data input system 210 comprises one or more input devices for the user to enter the logging data and the actual composition of the assayed sample determined by the XRF analysis. The input system 210 is arranged to receive the field logging data as percentages of logged material types, which the output device 240 then
- 15 displays in display areas 612 and 614 of Figure 6. The controller 220 then calculates an estimated composition of the logged material types and the output device 240 displays the estimated compositions in display areas 616 and 620. The output device 240 also presents the assay composition data in display areas 618 and 620.
- 20 Other information logged by the geological such as sample colour, shape, and texture can also be displayed, as shown in display area 622.

- The data input system 210 also comprises data storage for storing entered data, in this example the storage device 224. It will be appreciated that the data input system 210
- 25 may instead or additionally include other components or devices capable of receiving, or facilitating the receipt of, compositional data for the logged and assayed sample by the system 200.

- Before discussing the operation of the system 200 in more detail, a process for
- 30 obtaining the predetermined criteria, according to which the logging data is automatically validated, will be described.

**Validation Criteria**

- 35 In general terms, validation of the logging data involves adjusting the data so that its corresponding estimated composition conforms closer to the actual composition of the

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assayed sample. However, validation does not only seek to minimise the discrepancy between the estimated composition and the assayed composition; several geological and physical constraints ought to be satisfied for the validated composition to be accurate and meaningful. Thus, the validation should be performed according to  
5 predetermined validation criteria.

For example, the estimated compositions of logged samples can be adjusted by iteratively substituting or swapping one material type for another because a material type may have been incorrectly logged due to similar physical characteristics to  
10 another material type, such as colour and hardness. However, for geological integrity, a material type in the logging data should only be substituted for another material type if the interchanged material types have a common attribute. Therefore, a validation criterion may relate to only specific material type swaps being allowed.

15 As another example, some material types such as friable materials may exist in trace amounts only and so may not have been visible in the logged sample. Therefore, another validation criterion may relate to allowing friable material types to be added only when absolutely necessary to balance the assay values.

20 In yet another example, some material types such as pisolite are physically distinctive and their presence or absence should be obvious in the logged sample. Therefore, a further predetermined criterion may relate to prohibiting these materials from being removed or added if originally present or absent, respectively, in the logging data. Validation criteria to be used in the system 200 may be formulated by examining the  
25 past validation patterns of geologists. In other words, previously logged and subsequently validated compositions can be used as machine training data for the system 200.

### 1. *Substitution Rules*

30 In that regard, the validation criteria according to a specific embodiment of the invention was developed utilising a team of geologists, who were asked to validate incorrect logging data comprising naturally occurring errors, and deliberately included errors. Step-by-step changes from the logged compositions to the validated  
35 compositions were recorded. At each step, the geologists swapped a specific percentage of one material type for another material type with similar physical

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characteristics, while reducing the discrepancy between the estimated compositions and actual compositions. The material types swapped and the difference between each element or compound of the estimated composition and a corresponding element or compound of the actual composition was noted at each step, thus allowing incremental improvements to be observed.

These differences are stored as an n-element vector, where “n” is the number of elements or compounds (or collectively, “components”) in the compositions. In this example, the components in the composition comprise: Fe, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, P, S, Mn, MgO, TiO<sub>2</sub>, CaO, Total loss-on-ignition (LOI), goethite-bound water (LOI425), and kaolinite associated water (LOI650).

A normalisation was applied by dividing the vector by the maximum magnitude vector element so all elements lie in the interval [-1, 1]. Then, each vector element was rounded to the nearest 0.2, resulting in a normalised assay error vector.

For a given normalised assay error, there is therefore an associated percentage of one material type removed, and the same percentage of another material type added. From this, a database of material type substitution rules can be developed, which define allowable material type substitutions when validating logged compositions. Each rule is represented by a key formed from:

- the normalised assay error;
- the material type with increased percentage;
- the material type with reduced percentage; and
- the class of stratigraphy containing the interval.

Each substitution rule is also associated with a weight based on the percentage of the material type substituted. If it is found that two or more substitution rules have identical keys, they may be merged and the sum of their associated weights added. Thus, repeated observations of a particular substitution results in the corresponding substitution rule being associated with a larger weight. Notably, rounding the normalised assay error vector to the nearest 0.2 (or other value) increases the likelihood of rules being merged, thus reducing the size of the substitution rules database.

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The logging data validated was divided into three stratigraphic classes: detritals; mineralised bedded; and shales. Samples for each of these classes were obtained from a known site with materials corresponding to the respective class. Because some material type swaps will be confined to a particular class, it is also sensible for the substitution rules to be separated into different classes. For example, substituting ochreous goethite for clay is commonplace in detritals, but geologically unusual in bedded strata, where ochreous goethite would instead be substituted for shale.

The separation of substitution rules into different classes also allows different weights to be assigned to the same substitution with the same assay error in different stratigraphic classes. It was also found that the most common material type swaps include: GOE  $\leftrightarrow$  HGM, SHL  $\leftrightarrow$  HGF, GOL  $\leftrightarrow$  SHL, and GOL  $\leftrightarrow$  HGF.

## 2. Association Rules

The development of the substitution rules also provided information concerning which material types were commonly logged together. This information may assist in understanding the geological context of the different material types, which may provide a basis for further validation criteria. In this regard, the Apriori algorithm may be used to determine “association rules” from compositional data previously logged and validated on the assumption that geologists would have selected geologically valid combinations of material types.

In use, the Apriori algorithm receive past logged compositions and/or validated compositions as input, and determine the association rules whereby logging a material type X should lead to another material type Y being present in the logging data. Each association rule has a confidence value and a support value. The confidence value is the percentage of compositions containing material type X that also contain Y, while the support value is the percentage of all compositions containing both X and Y.

In this example, the data set used for the Apriori algorithm included logged and validated compositions for over 60,000 drilling intervals. The Apriori algorithm was also utilised independently for each of the three stratigraphic classes, since material types and/or association rules may vary according to stratigraphy. For example, where kaolinite is present, depending on the stratigraphic class, the kaolinite should be logged as either the clay type (detritals) or the shale type (bedded). As another example,

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banded iron formation should only be logged in bedded strata class, and therefore should not be logged elsewhere.

Association rules were developed with a minimum support value of 0.1% (per stratigraphic class), and a minimum confidence value of 0.1%, in order to include only significant trends in compositions. From the association rules, a list of subsets of geologically valid material types can be developed for each stratigraphic class, and ranked according to the most common subsets, as shown in Table 2 below. Notably, the frequent presence of clay in the detritals class, high grade hematite and goethite types in mineralised bedded class, and shale in shale intervals, is expected.

TABLE 2: Commonly co-logged subsets of material types

| Rank        | Detritals       | Mineralised bedded | Shale           |
|-------------|-----------------|--------------------|-----------------|
| 1 (pair)    | {CLA, GOE}      | {HGF, HGM}         | {GOL, SHL}      |
| 2 (pair)    | {CLA, GOL}      | {GOE, GOL}         | {GOE, SHL}      |
| 3 (pair)    | {CLA, GOV}      | {GOE, HGM}         | {GOE, GOL}      |
| 1 (triplet) | {CLA, GOE, GOL} | {GOE, HGF, HGM}    | {GOE, GOL, SHL} |
| 2 (triplet) | {CLA, GOL, GOV} | {GOL, HGF, HGM}    | {GOE, HGM, SHL} |
| 3 (triplet) | {CLA, GOE, HGM} | {HGF, HGH, HGM}    | {GOL, HGM, SHL} |

The validation criteria discussed above, including the material type substitution rules and the association rules, are stored as a database in the storage 224 of the system 210 together with the logging and assay data, as shown by blocks 410-418 in Figure 4. The data validation controller 220 can thus refer to these rules when executing a validation process.

#### Application of Validation Criteria

Applications of the validation criteria during operation of the system 200 according to embodiments of the invention will now be discussed.

In general terms, the substitution rules and association rules developed above are used to assist in determining validated compositions. Other physical information logged during examination of the logged sample, such as colour and hardness, may also be used. In this example, as an outcome of the validation process, the controller 220 causes a set of proposed validated compositions to be presented as options displayed on the output device 240 for the user to select. In this way, the geologists' knowledge

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and experience are maintained during the validation process. However, the system 200 provides the advantage that potential validated compositions may be quickly and accurately determined by the system 200, compared to conventional labour-intensive methods of validation. This may significantly reduce time and costs, and may also  
5 improve consistency between geologists.

Once the logging data and the actual composition of the assayed sample are entered into the system 200, i.e. the display areas 612 and 618 (Figure 6), the user can press the button 632, using an input device, to cause the system 200 to execute a validation  
10 process. Note that before the commencement of the validation process, the current and previous logging data in display areas 628 and 630, respectively, are the same as the original field logging data in display area 612.

Figure 3 shows a functional block diagram of the data validation controller 220,  
15 comprising modules to execute specific tasks or processes in accordance with the validation process. Figure 5 show a flow chart of the validation process 500 for validating the logging data of a logged sample according to an embodiment. The process 500 comprises multiple sub-processes for adjusting the logging data, including: a material type substitution process 510; and an optimisation process 520;  
20 an intermediate state penalty process 530; and a final selection process 540.

### *1. Material Type Substitution Process*

The controller 220 comprises a material type substitution selector 320 arranged to  
25 execute the material type substitution process 510. With reference to Figure 9, the process 510 involves identifying one or more material type substitution rules that satisfy a selection criterion or condition. In particular, the selector 320 accesses the material type substitution rules stored in the database 416, and searches the database 416 to select substitution rules according to information provided by a composition data  
30 comparator 310. The substitution rule selected are those that have a particular component of the logged composition that satisfies an error condition, wherein the error condition is based on the comparison between the compositions of the logging sample and assayed sample (step 512). Note that in this example, the step 512 is a specific implementation of the step 150 in Figure 1.

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In relation to the error condition, recall that each substitution rule was represented by a key formed from a normalised assay error, a material type with increased percentage, a material type with reduced percentage, a stratigraphy class, and a weight (i.e. the total amount of material swapped according to that assay error vector during development of the validation criteria). Also recall that the controller 220 estimates a composition of the logged sample based on the percentage of the material types logged. Therefore, in step 512, the comparator 310 retrieves the estimated composition of the logged sample and the actual composition assayed sample, from respective storages 410 and 412, and compares them. The difference in the composition values is displayed in display area 624 of the display (Figure 6). The comparator 310 then determines which component in the estimated composition satisfies a predefined condition based on the comparison. In this example, the predefined condition is the components with the greatest percentage error to be corrected (step 514). This is deemed the "major error component", and corresponds to the component of an assay error vector for the logged/estimated composition (or the "current assay error vector", for convenience) with the greatest magnitude.

Then, in this example the material substitution selector 320 retrieves the selected substitution rules from the database 416 in three phases according to an embodiment of the substitution process.

In the first phase, the selector 320 retrieves the substitution rules with a major error component of  $\pm 1$  with respect to the same component of the assay error vector, i.e. rules that appear to attempt to rectify the same largest component error according to the training data (step 516). If the major error component in the rule has an opposite sign to the major error component of the current assay error vector, the former is inverted by negating its assay error and switching the material type that was added and the material type that was removed.

Then, any substitution rules that specify removing material types that do not exist in the logged composition are discarded. Further, the angle between the current assay error vector and each remaining normalised assay error vector is determined, and substitution rules with an angle greater than for example 45 degrees are preferably disregarded. This is because although the major error components of current assay error vector and the remaining substitution rules are the same, the other assay error elements may be significantly different.

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The selector 320 then applies the substitution rules that satisfy these error conditions to the logged composition and generates a set of modified logged compositions, which for convenience may be referred to as "intermediate states" (step 518). Any duplicate  
5 substitution rules are merged and their weights summed. The selector 320 then sorts the list of potential substitution rules by the weight.

In step 520, in a similar manner to the first phase, the selector 320 then executes  
10 second phase of the selection criterion, involving identifying the component of the current assay error vector with the second greatest magnitude and applying the same error conditions to produce a list of substitution rules.

Similarly in the third phase, the component of the current assay error vector with the  
15 third greatest magnitude is then identified to produce a further list of substitution rules.

Using the three largest error components of the logging composition provides  
robustness to errors, and allows the selector 320 to select rules that are optimal for  
three major error components to provide a better overall solution.

20 In this example, by the end of the material type substitution process 510, a set of substitution rules would have been selected. The controller 220 then applies material type substitutions to the logging data in accordance with each selected substitution rule. Thus, a series of intermediate states of the logging data is generated. However, if  
25 a substitution would result in a set of material types matching those of a composition from an earlier state, the state can be discarded to avoid revisiting a previously processed state.

The material type substitution process 510 relates to determining feasible material type  
30 swaps. These steps only alter the set of logged material types, not the actual percentages of those material types.

## 2. Optimisation Process

The validation process 500 further comprises an optimisation process 520 performed  
35 by a material type percentage optimiser 330, where the actual percentages of logged material types may be modified according to particular conditions. In this example, the

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modification is performed on the intermediate states of the logging data generated from the process 510.

5 The optimisation process 520 involves adjusting the proportions or percentages of the material types of the logging data within a set of constraints stored in the storage 224.

The process 520 seeks to find optimal percentages for each material type that minimises assay error and changes in lump percentage and hardness, as a result of potential adjustments of the material types, compared to the original logging data.

10 With particular reference to Figure 10, the process 520 involves using an optimisation function (step 522), wherein the optimiser 330 calculates proposed optimum percentages for each material type by minimising a cost function 524 and applying constraints 526. In general terms, the cost function provides an indication of a degree of error that would result from a proposed adjustment to a logged composition. This  
15 may be done, for example, by evaluating an amount of undesirable deviation from the original logged sample. Evaluation of the cost function is performed by a cost evaluating component 332 of the optimiser 330.

According to this embodiment, the cost function is a function of three error  
20 components: assay error ( $E_{\text{assay}}$ ), hardness error ( $E_{\text{hardness}}$ ) and lump error ( $E_{\text{lump}}$ ). Thus, lower cost function values are better. Each component of the cost function will now be discussed in more detail.

Firstly, in relation to the assay error ( $E_{\text{assay}}$ ), the cost function utilises an assay error  
25 tolerance factor, which is the absolute assay percentage error relative to a predetermined tolerance value for each component of the logged composition. An assay error tolerance factor of 1 represents the largest allowable absolute assay error for that component.

30 The assay error tolerance values are predetermined and set independently for each component, and may vary according to different requirements. These are also stored in the storage 224. For example, a lower level of accuracy for validation of low-grade (waste) drilling intervals may be acceptable. In one example, the following assay error tolerance values may be used:

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| Component                      | Assay Error Tolerance |
|--------------------------------|-----------------------|
| Fe and SiO <sub>2</sub>        | 2.5%                  |
| Al <sub>2</sub> O <sub>3</sub> | 2%                    |
| Total LOI                      | 1.5%                  |

The controller 220 then retrieves the predetermined error tolerance values from the storage 224 and displays them for each composition in display area 626 of Figure 6.

Note that if the differences in row 624 exceed their respective predetermined tolerance in row 626, the difference is highlighted. All solutions of the cost function having theoretical assay error tolerance values within the respective tolerance of the laboratory assay value are considered equally valid.

Further, a minimum assay error tolerance factor of 0.5 is enforced during optimisation.

This avoids unnecessarily optimising the compositions to fractions of a percent when compositions are generally presented to the user to the nearest integer percentage for simplicity.

For an element or compound 'a' (i.e. Fe, SiO<sub>2</sub> etc.), laboratory assay value 'L', theoretical assay value 'T', error tolerance value 'ε', and tolerance factor weighting 'f', the assay error component E<sub>assay</sub> is given by:

$$E_{assay} = \sum_a \frac{\max(|L_a - T_a|, \epsilon_a/2)}{\epsilon_a} * f_a$$

Errors in Fe, SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> are more significant in terms of grade than for other elements which generally occur in trace amounts. Therefore, their respective tolerance factors may be doubled before summing the tolerance factors for all elements.

Secondly, the mineral hardness error component (E<sub>hardness</sub>) is taken into account to preserve information regarding the RC chip hardness recorded in the logging data. In this regard, each material type has a theoretical or predefined hardness value. The theoretical hardness of a sample can thus be estimated using the percentages of material types estimated and logged, and the predefined hardness value for respective material types. Therefore logged material types for a drilling interval (and their intermediate states) can also be divided into three categories: hard, medium and friable.

For each hardness category, the optimiser 330 calculates the differences in the hardness values between the original logging data and proposed optimised data, minus

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a grace change in hardness of 10%, to allow for minor changes in hardness without penalty. To calculate the hardness error component, a change in hardness  $\Delta_h$  is computed as follows:

$$\Delta_h = \sum_{b \in \{H, M, F\}} \max(|b_{logged} - b_{optimised}| - 0.1, 0)$$

5

The (total) change in hardness  $\Delta_h$  therefore comprises a sum of the max function calculation for each hardness category. The max function prevents negative values from being included after subtracting the grace change in hardness.

10 The hardness error component  $E_{hardness}$  is then provided using a Gaussian function:

$$E_{hardness} = \exp\left(-\frac{\Delta_h^2}{0.3 * 0.25^2}\right),$$

15 The constant value of 0.3 in the above function is used to adjust the weighting, and was determined empirically. The standard deviation value of 0.25 was derived from the training data.

Thirdly, regarding lump error ( $E_{lump}$ ), each material type also has a theoretical lump percentage. A lump percentage for each material type provides a breakdown of the ore into lump (i.e. particles greater than a particular size, such as 3mm, 4mm, 5mm, 6mm, or more preferably 6.3mm or 0.25" in diameter) and fines product. In contrast to the hardness measure of the logging data, which is a qualitative material property, the lump percentage is a quantitative measure. Notably, for the same material type, the lump percentage (like other properties) may vary across different sites, and material type grades can also vary for the resulting lump and fines product at the same site.

25 Typically, the Fe grade is higher for lump product.

Since lump and fines products are marketed separately, changes in the lump percentage as a result of a logged composition being modified may have significant commercial implications. Thus, the lump error is taken into account in an attempt to maintain similarity between the theoretical lump percentage for the proposed optimised data and the theoretical lump percentage of the original logging data.

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In this embodiment, a sigmoid function as shown below is used to calculate the lump error component  $E_{lump}$  from the change in the lump percentage  $\Delta_l$ :

$$E_{lump} = 0.5 + \frac{1}{2 + \left(\frac{\Delta_l}{50}\right)^2}$$

- 5 The denominator of 50 in the squared term controls the rate of drop-off of the error value. The result ranges from 0.5 (due to the constant term of 0.5) to 1 (when  $\Delta_l = 0$ ).

The cost function used in the optimisation process is then derived using  $E_{assay}$ ,  $E_{hardness}$  and  $E_{lump}$  as follows:

10

$$E_{total} = \frac{E_{assay} * E_{hardness}}{E_{lump}} * (1 + n)$$

In the above formula, 'n' is the number of components with theoretical values arising from the proposed optimised data varying from the assay values by more than the tolerance amount.

15

The optimisation function may be implemented using the ALGLIB™ optimisation package provided by the ALGLIB Project. The optimisation function uses the cost function and boundary and/or linear equality constraints.

20

The boundary constraint may ensure that the percentage for each material type lies between 0 and an upper bound, which is the percentage of that material type that would cause the theoretical value for any element to be exceeded by the error tolerance. In other words, this ensures that an error tolerance for any component cannot be exceeded by a single material type.

25

Further constraints may be applied to specific material types, for example, textural types such as pisolite, where only a small variation in material type percentage is allowed. Moreover, during logging, textural types are rarely confused with other material types and thus should not be removed. Such specific material type constraints may prevent the entire removal of textural material types, thus preserving accuracy. Finally, a linear constraint may also be used to ensure that the material types' percentages sum to 100%.

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According to a specific embodiment, the optimisation process 520 executed by the optimiser 330 is an iterative function. In each iteration, the current state is formed from the material type percentages of the intermediate state, and the gradient of the cost function is estimated from the intermediate state at that iteration.

5

The dimensionality of the gradient of the cost function is equal to the number of material types being examined. In other words, the cost function has a number of dimensions equal to the number of material types being examined. The gradient in each dimension is estimated by:

10

- first, temporarily altering the intermediate state for this dimension by adding 1% to the corresponding material type value, while reducing the percentages of the other material types by  $1/(N-1)\%$ , where  $N$  is the number of material types, thus ensuring that the total composition remains at 100%;

15

- second, evaluating the cost function at the altered intermediate state for this dimension; and

20

- third, calculating the difference between the cost function value for the intermediate state, and the cost function value for the altered intermediate state for this dimension.

The gradient of the cost function is used to determine the proportions in which the material type percentages will be changed. In this example, the magnitude of these changes are controlled by a constant step length provided by the ALGLIB™ optimisation algorithm, and the supplied constraints are used to enforce bounds on the magnitude such that the percentages of each material type remain valid as described above.

30

The optimisation function iterates until a condition is met, for example:

35

- when the magnitude of the gradient is less than a predetermined value (i.e. the cost function has reached a local minimum from where there is no clear direction for improvement); or
- when the change in the cost function in successive iterations is less than a predetermined value (i.e. the cost function has reached a local minimum); or

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- where the change in composition in successive iterations is less than a predetermined value (i.e. there is negligible change in material type percentages); or
- 5      • a maximum number of iterations, e.g. 10, 20, 30, has been performed.

Using the cost function and constraints according to the embodiment described above, the optimiser 330 provides a single solution, for each intermediate state resulting from the material type substitution process 510, regardless of the initial percentages of each  
10      material type. This produces optimised intermediate states (step 522). Moreover, when solved for a particular element in the logged composition, a resulting value of the cost function may be used to rank the intermediate states. This will be discussed in more detail below.

15      Notably, when percentages of material types are modified according to the optimisation process 520, it is not necessary to compensate for the change in percentage since the optimisation process will find the appropriate percentages of material types of the intermediate states that best fits the laboratory assays, hardness distribution and the lump percentage.

20

### *3. Intermediate State Penalty Process*

After the optimisation process 520, the validation process 500 comprises executing an intermediate state penalty process 530, which in this embodiment is performed by a  
25      penalty determiner 340 of the controller 220.

With reference to Figure 10, in the penalty process 530, once the material type percentages have been optimised, the penalty determiner 340 determines whether a penalty applies according to the various geological conditions (step 532), and applies a  
30      corresponding penalty if applicable. In particular, an intermediate state penalty is applied to geologically unusual combinations of material types in the intermediate state.

The intermediate state penalty according to this embodiment is in the form of a numeric multiplier applied to the cost value of an intermediate state determined from the  
35      optimisation process 520. Large penalty multipliers (e.g. 4-8) may be used so that a prospective match of an intermediate state with the assayed composition must be to a sufficient degree to counteract the penalty.

Several geological conditions such as stratigraphy, conflicting and prohibited material types, texture, hydration, and hematite-goethite continuity are used as the basis for penalties. In this example, where the same condition is violated multiple times, the  
5 penalty determiner 340 applies penalties repeatedly for each violation. Various penalty types according to specific embodiments are discussed in more detail below.

- 10 • *Stratigraphy.* A penalty is applied when substitution rules from stratigraphic classes other than that of the logged composition are selected. Preferably, a penalty is applied rather than disallowing the use of rules from other stratigraphic classes, in order to broaden the set of possible rules, particularly in situations where there are few rules with similar assay errors to the logged or intermediate state.
- 15 • *Conflicting and prohibited material types.* Some material type combinations are geologically incompatible. For example, there are two kaolinite types: clay in hydrated and detritals intervals; and shale in unhydrated intervals. These two kaolinite types should not be logged together or logged in the wrong stratigraphy. In practice, doing so may lead to geological misunderstandings  
20 during modelling, thus a penalty is applied to prevent these situations. A penalty is also applied for combining material types predominantly comprising one element, e.g. gibbsite (alumina) and quartz (silica), in place of a kaolinite type which is high in both elements.
- 25 • *Distinctive material types.* Penalties are applied to prevent the complete removal of a material with distinctive texture, or addition of a material type with distinctive appearance if not originally logged, since the geologist is likely to have logged the material type if present.
- 30 • *Hydration.* Some material types such as vitreous goethite have characteristics arising from hydration. Therefore, these material types should only be included in a composition if the drilling interval associated with the logged data being validated is in a known hydrated zone. Accordingly, a penalty is applied if these material types are included in compositions from non-hydrated zones.  
35 Conversely, a penalty is applied if a material type, which never occurs in the hydrated zone, is included in a composition from a known hydrated zone.

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- *Hematite-goethite continuity.* Recall that in Table 1 above, various compositions of hematites and goethites are shown at different levels of hardness (friable, medium, and hard). In reality, such compositions occur naturally in a continuous spectrum of hardness. Thus, it is unusual for the hard H2H type to be logged with the friable H2F type without the medium H2M type also being logged. A penalty is applied when the continuous spectrum of hardness is broken in the logging data or intermediate states. Similarly, Table 1 also shows predominantly goethite material types of varying hardness (GOV, GOE, GOL) and intermediate hematite-goethite types (HGH, HGM, HGF). It is unusual for a predominantly goethite material types to be logged alongside a predominantly hematite material type if an intermediate type is not also logged; thus a penalty is also applied in that situation.
- 15 For each intermediate state, the penalties described above are accumulated to provide an intermediate state penalty (step 534). This total penalty is then multiplied by the respective cost function value calculated from cost function used in the optimisation process 520 (step 536). This product is used to rank the intermediate states (step 538). The validation controller 220 then selects a predefined number of the highest ranked
- 20 intermediate states (step 539), i.e. the intermediate states with the lowest product of their respective cost function values and intermediate state penalties. For example, between around 30-50 of the highest ranked intermediate states may be selected, or more preferably between 35-45, or more preferably around 40.
- 25 With particular reference to Figure 5, in this embodiment, the validation process 500 is a partially iterative process. Thus, after the intermediate state penalty process 530, the controller 220 causes the process 500 to be repeated from the substitution process 510 using the selected (penalised) intermediate states as a basis for the next iteration previously selected. In other words, the selected intermediate states take the place of
- 30 the logged composition in the next iteration, and are subjected to the same process (i.e. compared with the actual composition, substitution rule selection, optimisation, intermediate state penalty etc.) The process 500 may be repeated any suitable or predetermined number of times, for example 2 to 5 times, each time using the resulting selected intermediate states in place of the logged composition or previous selected
- 35 intermediate states.

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Alternatively, if there is no change in the highest ranked composition after an intermediate state penalty process 530 in one of the iterations, the controller 220 will commence a final selection process 540 to select final proposed validations.

#### 5      4. *Final Selection Process*

With reference to Figures 5 and 11, a final penalty determiner 350 executes a final selection process 540, including determining whether to apply final penalties that may not have been appropriate to apply to intermediate states during iteration. With  
 10 particular reference to Figure 11, the final selection process 540 in this example includes determining whether colour, weight, substitution, chip, stratigraphy or association penalty applies to penultimate states (step 541). For example, the association penalty may involve applying penalties for unlikely material type associations. For convenience, the intermediate states generated immediately prior to  
 15 the final selection process 540 may be referred to as the "penultimate states".

Recall that during logging, colours associated with each region of interest (or drilling interval) may also have been logged. In this example, step 541 of the final selection process 540 comprises a colour penalty process 542, which involves examining, for  
 20 each material type, the logged colours of the training data. More specifically, the colour penalty process 542 comprises:

- For a particular material type  $m_N$  in the penultimate composition, examine past logging data, identify those that also logged  $m_N$ , and the colour logged for the  
 25 associated drilling interval.
- Then, determine a percentage of the past data identified with  $m_N$  that have also logged the same colour as the colour logged with  $m_N$ .
- Multiply the percentage from the preceding step with the percentage of the  
 30 material type in the penultimate composition.
- Sum the value obtained from the preceding step for all material types to determine colour penalty values  $p_{col}$ .

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A minimum colour penalty value of 0.5 is used to avoid small values arising where little training data is available. Therefore, the colour penalty values  $p_{\text{col}}$  lie in the interval [0.5, 1].

- 5 Similarly, according to a specific embodiment, the frequencies of the logged chip shapes (angular, sub-angular, rounded, sub-rounded, or combinations thereof), and stratigraphic class for each material type may be examined to determine other penalties, such as a chip shape penalty  $p_{\text{chip}}$  and stratigraphic class penalty  $p_{\text{strat}}$ .
- 10 For example, the final penalty determiner 350 may be configured to determine  $p_{\text{chip}}$  by executing the following steps:
- retrieve the logged chip shapes of past logging data and determine the historic distributions of logged chip shapes for each material type from past data;
  - 15 • for each particular material type  $m_N$  corresponding to the penultimate composition, where  $N$  is the number of material types, determine the percentage of the past data identified with the material type  $m_N$  that also have logged the chip shape logged for the associated drilling interval;
  - 20 • multiply the determined percentage with the percentage of the material type in the penultimate composition;
  - sum the product of the percentages obtained from the previous step for all
  - 25 material types to determine the chip shape penalty  $p_{\text{chip}}$ .

In a further example, the final penalty determiner 350 may be configured to determine the stratigraphic class penalty  $p_{\text{strat}}$  by executing the following steps:

- 30 • determine the historic distributions of material types for stratigraphic classes from past data;
- for each particular material type  $m_N$  corresponding to the penultimate composition, determine the percentage of the past data identified with  $m_N$  that
  - 35 lie in the same stratigraphic class as the associated drilling interval;
  - multiple the determined percentage with the percentage of the material type in the penultimate composition;

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- sum the product of the percentages obtained from the previous step for all material types to determine the stratigraphy penalty  $p_{\text{strat}}$ .

- 5 A minimum chip shape penalty value of 0.5 is used to avoid unduly small values. A minimum stratigraphy penalty value of 0.5 is also used to avoid unduly small values. Thus the resulting chip shape penalty  $p_{\text{chip}}$  and stratigraphy penalty  $p_{\text{strat}}$  also both lie in [0.5, 1].
- 10 In this example, step 541 of the final selection process 540 also comprises a weight penalty determination step 544. Recall that each substitution rule is associated with a weight based on the percentage of the material type substituted. These weights are considered here, since material type substitutions that were more commonly made by geologists in past validation are preferred. The weight rule value 'w' is the sum of the
- 15 weights of the normalised substitution rules over all five iterations and will lie in the interval (0,5]. Larger weight rule values provide a smaller penalty.

Step 541 of the final selection process 540 further comprises a substitution penalty determination process 546. In this process, a further penalty is applied for the number

20 'S' of material types swapped to respect the geologist's original logging. In other words, a penalty is applied for making a higher number of material type substitutions. Notably, in this embodiment, adding one material type is considered 1 change, subtracting one material type is also considered 1 change and completely substituting one material type for another is considered 2 changes.

25 Lastly, step 541 of the final selection process 540 comprises an association penalty determination process 548. In this process, the material types in each penultimate composition is examined by utilising the association rules to penalise combinations of material types not seen in the past data used to develop the substitution rules. A score

30 is calculated based on the association rules and confidence values determined by the Apriori algorithm described above.

The score is computed for a set of N material types by first numbering all subsets of N-1 material types. For a given subset S, if an association rule exists for the subset, the

35 score is the highest confidence value between the individual material types  $m_1$  and  $m_2$ , where  $m_1 \in S$  and  $m_2 \notin S$ . If no such association rule exists, a similar process is performed for subsets of size N-2, and the score computed using the product of the two

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confidence values, each derived by taking into account one of the material types excluded from the calculation.

As an illustrative example, assume there is a combination of four material types in the logging data: A, B, C, D. An association rule for the set {A,B,C,D} does not exist in the association rules database 418, but an association rule does exist for the set {A,B,C}. The confidence values between individual material types may then be calculated using the Apriori algorithm to link the combination {A,B,C} to the absent type D. In particular, the confidence values between individual material types A-D, B-D and C-D are calculated. The score mentioned above is designated as the maximum confidence value out of A-D, B-D and C-D. Therefore,  $m_2$  is considered as D and A, B and C are in turn considered as  $m_1$ .

Further in this example, where there is no association rule for {A,B,C} or any other triplet, N-2 is considered. In this case, if there is an association rule for {A,B}, confidence values for the pairs A-C and A-D, or B-C or B-D, or A-C and B-D, or B-C and A-D, are calculated. The confidence values for each calculated pair is multiplied to obtain the score.

The confidence value, and therefore the association penalty  $p_{assoc}$ , are in the range (0,1] and is applied to the final penalty by dividing it by  $p_{assoc}$ .

The final penalty determiner 350 then determines (step 543) the final penalty  $p_{final}$  as follows:

25

$$p_{final} = \frac{1}{p_{col} * p_{chip} * p_{strat} * \max(1, S) * w * p_{assoc}}$$

Using the sum of the  $p_{final}$  value and the cost function value derived during the optimisation process 520, the controller 220 then ranks the penultimate states (step 545) and presents them to the user (step 547) in the form of adjusted material type percentages (see display areas 710 and 712 in Figure 7). In particular, this sum is mapped to an integer confidence value from 1 to 10, as shown in column 714 in Figure 7. In this example, the top ten ranked compositions are presented to the user or geologist as potential validated compositions on the output device 240.

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The geologist (or other operator) can then use the input system 210 to select one of the proposed validated compositions, and accept the composition as the final validated composition by selecting button 718. Upon acceptance, the controller 220 will cause the selected results to populate the display area 628, as shown in Figure 8, to check  
5 the discrepancy between the modified logging data and actual composition of the assayed sample. As shown in display area 624 of Figure 8, the discrepancy has reduced due to the validation process and final selection.

Embodiments of the invention are based on the realisation that during the validation  
10 process, it is appropriate to utilise a processing machine for some aspects of the logging data; however, for other aspects it is also appropriate to preserve the initial input by a user, since such input is likely to be correct. For instance, while it is appropriate to utilise a machine for adjusting the estimated compositions based on the material types logged, the machine processes for adjusting the compositions ought to  
15 be guided by the physical properties of the mineral sample logged and other known geological factors of the region of interest. Therefore, according to embodiments herein described, the proposed validated compositions may be those that depart least from the original physical properties logged as a result of the adjustments made to the logging data.

20 The system 200 also allows the user to modify the selected composition further if desired. In this embodiment, the user may modify the material type percentages by using the increase or decrease buttons 810. Once satisfied, the user can save the final validated composition.

25 Once a final validated composition has been saved, the process 500 may comprise a further step 550 of updating the training data that provides the validation rules to include the selected final validated compositions. This will also cause the more commonly selected substitution rules to be more preferable over time, due to the  
30 consequential increase in weight associated with repeatedly selected substitution rules.

Additions to the training data or validation criteria, including substitution and association rules, can also be made if particular scenarios are not yet accounted for by the validation rules. Moreover, specific factors such as the weight of material type  
35 substitution rules can be modified as needed.

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Preferably, the data validation controller 220 is also arranged to save data corresponding to each iteration of the validation process into data storage. Accordingly, the data validation process performed for a particular logged composition may be audited.

5

The performance of the system 200 (and method 100) was evaluated using two sets of experiments. The first experiment assessed the accuracy of the proposed validated compositions by using a group of geologists and analysing their acceptance of the proposed auto-validated compositions. In the second experiment, the system 200 (and  
10 method 100) was used for an entire deposit to examine the distributions of specific material types.

In the first experiment, a group of geologists used the system 200 to validate logged compositions from 1996 drilling intervals. In 1483 (or 74.3%) of the intervals, the  
15 geologists selected a proposed validated composition produced by the system 200 and accepted it as the final validated composition without further change. As the average time taken to validate an interval manually is 2 minutes, presenting an immediately acceptable composition is a significant time saving. Furthermore, of these selected final compositions, the composition with the highest confidence value was selected 833  
20 times (56.2% of the intervals) while the mean ranking of the selected composition was 2.1. This demonstrates that the geologists do not need to spend significant amounts of time examining the proposed compositions. Thus, presenting fewer options to the user can further simplify the validating process in future work.

25 It will be understood to persons skilled in the art of the invention that many modifications may be made without departing from the spirit and scope of the invention. For example, in variations of the method and system, the optimisation process 520 may be performed without having previously performed the material type substitution process 510. Further, the final selection process 540 may not include all the penalty  
30 processes 542 to 548 and/or may include other penalty processes. Furthermore, a person skilled in the art will appreciate that the method and system herein disclosed can be applied to samples other than those collected for the purposes of iron ore exploration, and thus the material types and compositions of the samples may be different from those described in the examples above.

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It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

- 5 In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the
- 10 invention.

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## CLAIMS

1. A method of validating logging data for a mineral sample obtained from a region of interest, the method comprising:
  - 5 obtaining logging data associated with a composition of the mineral sample, the logging data including one or more estimated material types present in the mineral sample;  
obtaining compositional assay data indicative of an actual composition of the mineral sample or another mineral sample provided from the region of interest;
  - 10 determining an estimated composition of the mineral sample based on the estimated material types;  
storing validation criteria in a data storage, the validation criteria defining allowable modifications to the estimated material types based on physical properties associated with the material types;
  - 15 comparing the estimated composition with the compositional assay data; and  
using a data validation controller to provide adjusted logging data based on: the comparison of the estimated composition with the compositional assay data; and the validation criteria.
- 20 2. The method of claim 1, wherein the logging data comprises an estimated proportion of each material type in the mineral sample.
3. The method of claim 1 or 2, wherein the logging data further includes at least one physical property of the mineral sample associated with the logging data.
- 25 4. The method of any one of the preceding claims, wherein the validation criteria comprises information indicative of material type substitution rules defining allowable material type substitutions according to which the logging data can be adjusted.
- 30 5. The method of claim 4, comprising using the data validation controller to adjust the logging data by substituting at least a portion of at least one material type in the logging data for at least one other material type according to one or more applicable material type substitution rules.
- 35 6. The method of claim 5, wherein prior to substituting at least a portion of the at least one material type, the method comprises selecting one or more of the applicable material type substitution rules by determining a component of the estimated composition that satisfies a predefined condition.

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7. The method of claim 6, wherein determining the component of the estimated composition that satisfies the predefined condition comprises determining the component of the estimated composition that has a greatest degree of difference from  
5 a corresponding component of the composition assay data.

8. The method of any one of claims 5 to 7, wherein adjusting the logging data produces one or more corresponding intermediate states of the logging data, the intermediate states having a theoretical composition and at least one theoretical  
10 physical property.

9. The method of any one of the preceding claims, comprising defining error tolerance values for one or more of: at least one component of the estimated  
15 composition; a hardness of the mineral sample; and a lump percentage indicative of a proportion of particles in the mineral sample that is greater than a particular size.

10. The method of claim 9, wherein adjusting the logging data comprises adjusting the estimated proportions of the material types or corresponding intermediate states  
20 without exceeding one or more of the error tolerance values.

11. The method of any one of claims 8 to 10, comprising adjusting the one or more corresponding intermediate states while minimising a degree of difference associated with the at least one physical property of the logging data and the at least one physical  
25 property of the theoretical composition.

12. The method of any one of claims 8 to 11, comprising associating each corresponding intermediate state with a penalty value and ranking the one or more corresponding intermediate states according to the penalty value, wherein the penalty  
30 value is determined based on one or more of the following:

a presence of incompatible material types in the one or more corresponding intermediate states;

a particular material type in the logging data being inconsistent with a geological context of the region of interest; and

35 a distinctive material type originally present in the logging data being removed, or a distinctive material type originally absent from the logging data being added, as a result of the processor adjusting the logging data.

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13. The method of claim 12, comprising selecting a predetermined number of the intermediate states according to ranking.

14. The method of claim 12 or 13, comprising repeating the method from the step of  
5 adjusting the logging data with the estimated composition being replaced with the selected intermediate states, in order to generate a plurality of penultimate states of the logging data.

15. The method of claim 14 comprising associating each penultimate state with a  
10 final penalty value and ranking the plurality of penultimate states according to the final penalty value, wherein the final penalty value is based on one or more of the following:  
at least one physical property of the logging data and at least one physical property of the theoretical composition;  
a total amount of material type substitutions experienced by each penultimate  
15 state; and  
a presence of incompatible material types in each penultimate state.

16. A system for validating logging data obtained for a mineral sample from a region of interest, the system comprising:  
20 a data input system arranged to receive:  
user input logging data associated with a composition of the mineral sample, the logging data including one or more estimated material types present within the mineral sample, and;  
compositional assay data indicative of an actual composition of the  
25 mineral sample, or another mineral sample provided from the region of interest, determined by assaying the or the other mineral sample;  
the system arranged to determine an estimated composition of the mineral sample based on the estimated material types;  
the system further comprising a data storage storing validation criteria defining  
30 allowable modifications to the estimated material types based on physical properties associated with the material types; and  
a data validation controller arranged to: compare the estimated composition and the compositional assay data, and adjust the logging data based on the comparison and the validation criteria.  
35

17. The system of claim 16, wherein the logging data comprises an estimated proportion of each material type in the mineral sample.

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18. The system of claim 16 or 17, wherein the logging data further includes at least one physical property of the mineral sample associated with the logging data.
19. The system of any one of claims 16 to 18, wherein the validation criteria  
5 comprises information indicative of material type substitution rules defining allowable material type substitutions according to which the logging data can be adjusted.
20. The system of claim 19, wherein the controller is arranged to adjust the logging data by substituting at least a portion of at least one material type in the logging data  
10 for at least one other material type according to one or more applicable material type substitution rules.
21. The system of claim 20, where the system is arranged such that prior to substituting at least a portion of the at least one material type, the system selects one  
15 or more of the applicable material type substitution rules by determining a component of the estimated composition that satisfies a predefined condition.
22. The system of claim 21, wherein the system is arranged to determine the component of the estimated composition that satisfies a predefined condition by  
20 determining the component of the estimated composition that has a greatest degree of difference from a corresponding component of the composition assay data.
23. The system of any one of claims 20 to 22, wherein the controller is arranged to produce one or more corresponding intermediate states of the logging data as a result  
25 of adjusting the logging data, the intermediate states having a theoretical composition and at least one theoretical physical property.
24. The system of claim 26, wherein the controller is arranged to adjust the estimated proportions of the material types or one or more corresponding intermediate  
30 states without exceeding one or more error tolerance values.
25. The system of claim 24, wherein the error tolerance values are associated with one or more of: at least one component of the estimated composition; a hardness of the mineral sample; and a lump percentage indicative of a proportion of particles in the  
35 mineral sample that is greater than a particular size.
26. The system of any one of claims 23 to 25, wherein the system is arranged to modify the one or more corresponding intermediate states while minimising a degree of

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difference associated with at least one physical property of the logging data and at least one physical property of the theoretical composition.

27. The system of claim 26, wherein the system is arranged to associate each  
5 corresponding intermediate state with a penalty value and rank the one or more corresponding intermediate states according to the penalty value.

28. The system of claim 27, wherein the system is arranged to determine the penalty value based on one or more of the following:  
10 a presence of incompatible material types in the one or more corresponding intermediate states;  
a particular material type in the logging data being inconsistent with a geological context of the region of interest; and  
a distinctive material type originally present in the logging data being removed,  
15 or a distinctive material type originally absent from the logging data being added, as a result of the processor adjusting the logging data.

29. The system of claim 28, wherein the system is arranged to select a predetermined number of the intermediate states according to ranking.  
20

30. The system of claim 29, wherein the system is arranged to adjust the logging data with the estimated composition being replaced with the selected intermediate states, in order to generate a plurality of penultimate states of the logging data.

25 31. The system of claim 30, wherein the system is arranged to associate each selected intermediate state with a final penalty value and rank the plurality of penultimate states according to the final penalty value.

32. The system of claim 31, wherein the final penalty values are determined based  
30 on one or more of the following:

at least one physical property of the logging data and at least one physical property of the theoretical composition;

a total amount of material type substitutions experienced by each penultimate state; and

35 a presence of incompatible material types in each penultimate state.

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33. The system of claim 32, wherein the system is arranged to select a predetermined number of the penultimate states with the lowest final penalty value, and present the selected penultimate states to a user.
- 5 34. The system of any one of claims 16 to 33, wherein the input system comprises an input device arranged to allow the user to select at least one of the selected penultimate states to for acceptance as a final validated composition.
- 10 35. A method for validating the composition of a mineral sample comprising the steps of:
- receiving user input data comprising observed physical properties and estimated material properties of a mineral sample;
  - receiving assayed data comprising composition of a mineral sample;
  - generating a theoretical composition of the sample from the estimated material
  - 15 properties;
  - calculating a difference between the composition of the mineral sample and the theoretical composition;
  - automatically adjusting the estimated material properties to reduce the difference and maintain the observed physical properties.
- 20

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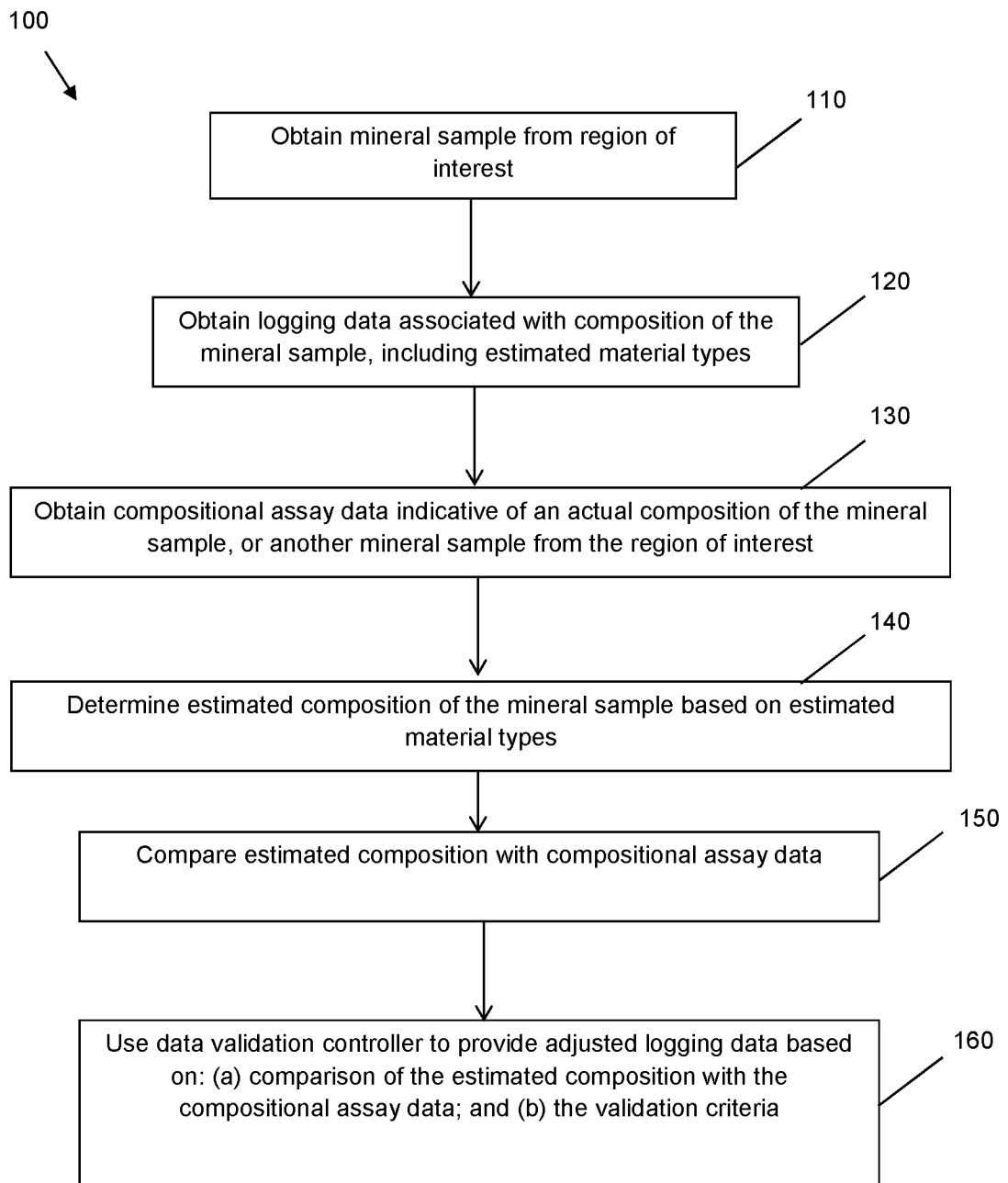


FIGURE 1

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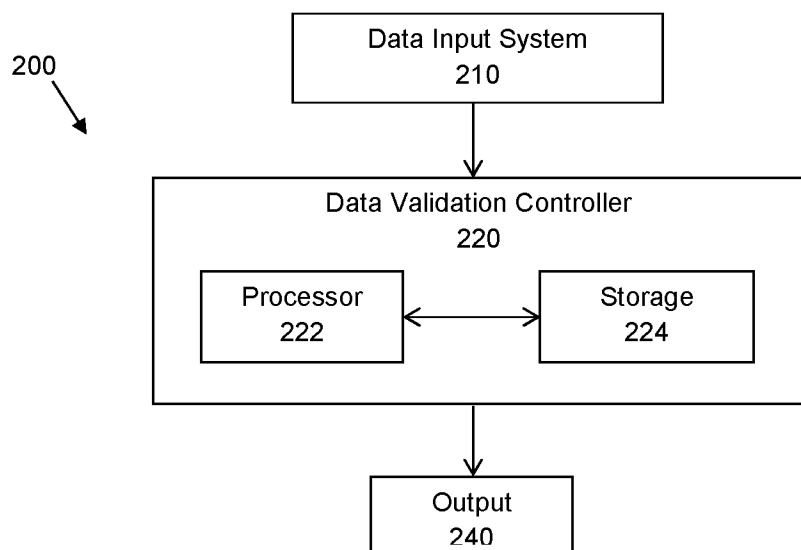


FIGURE 2

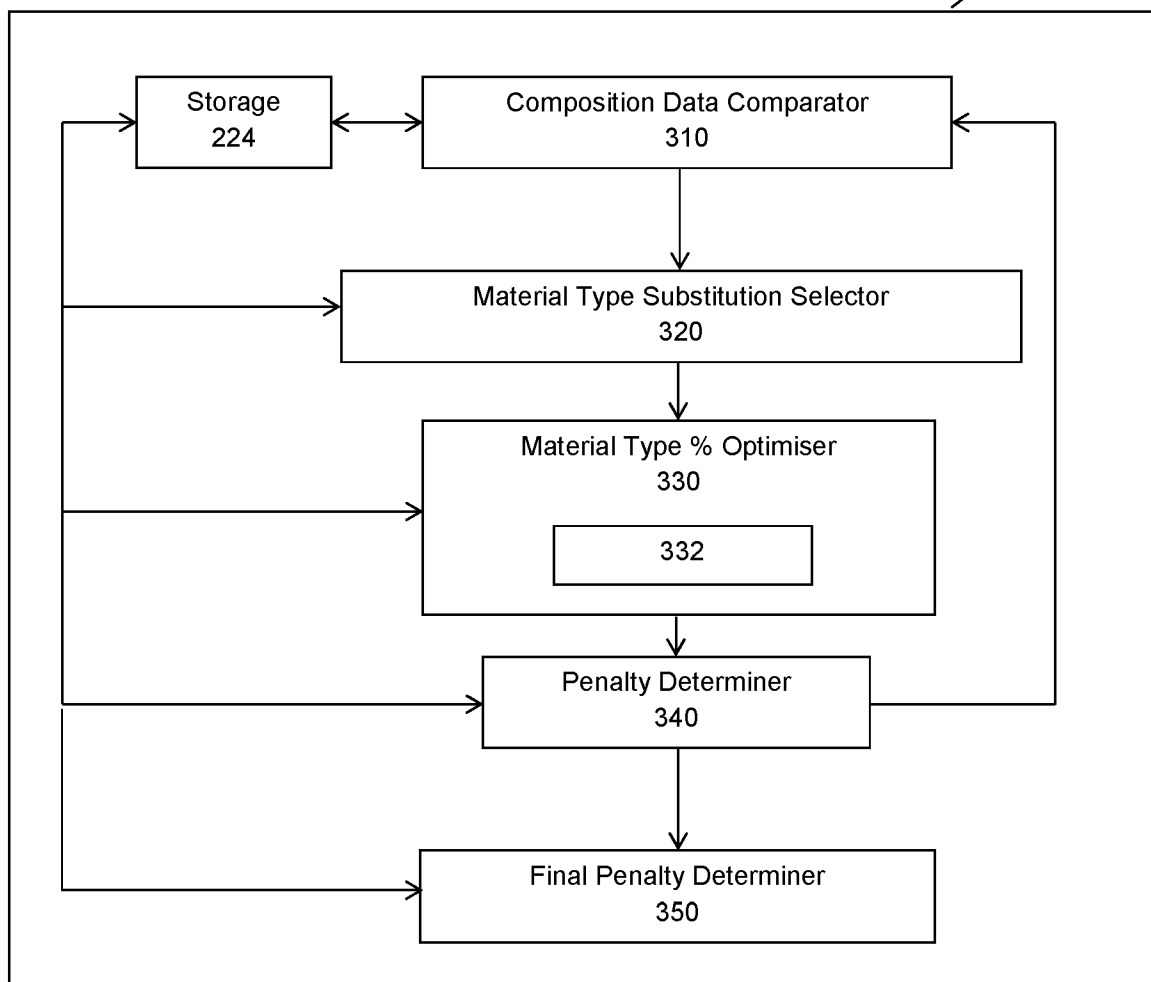


FIGURE 3

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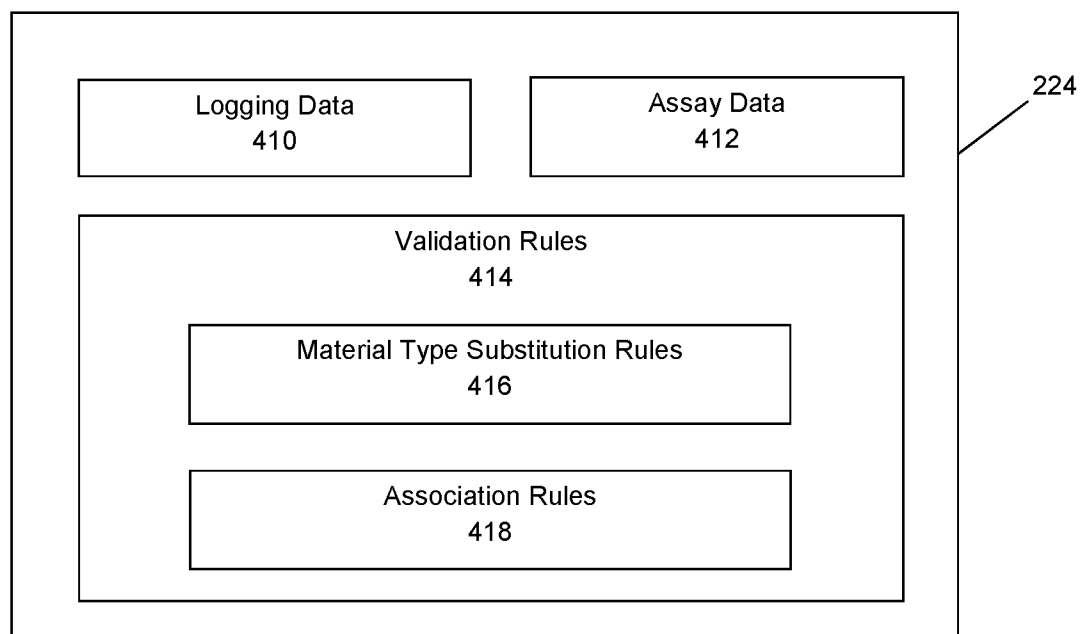


FIGURE 4

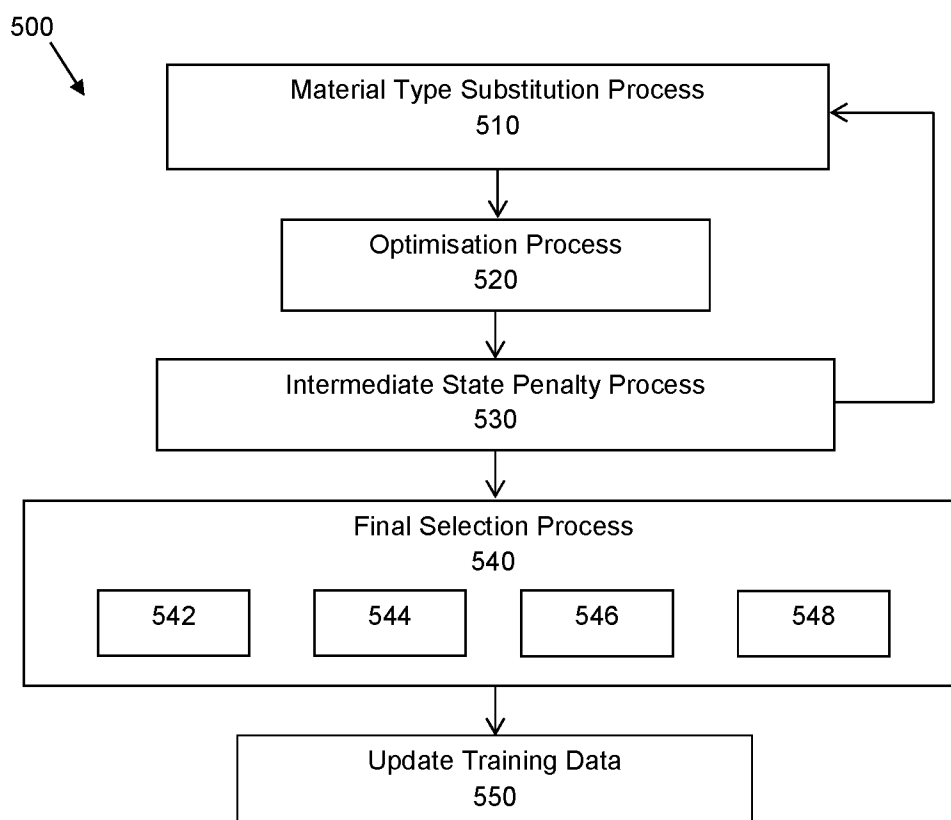
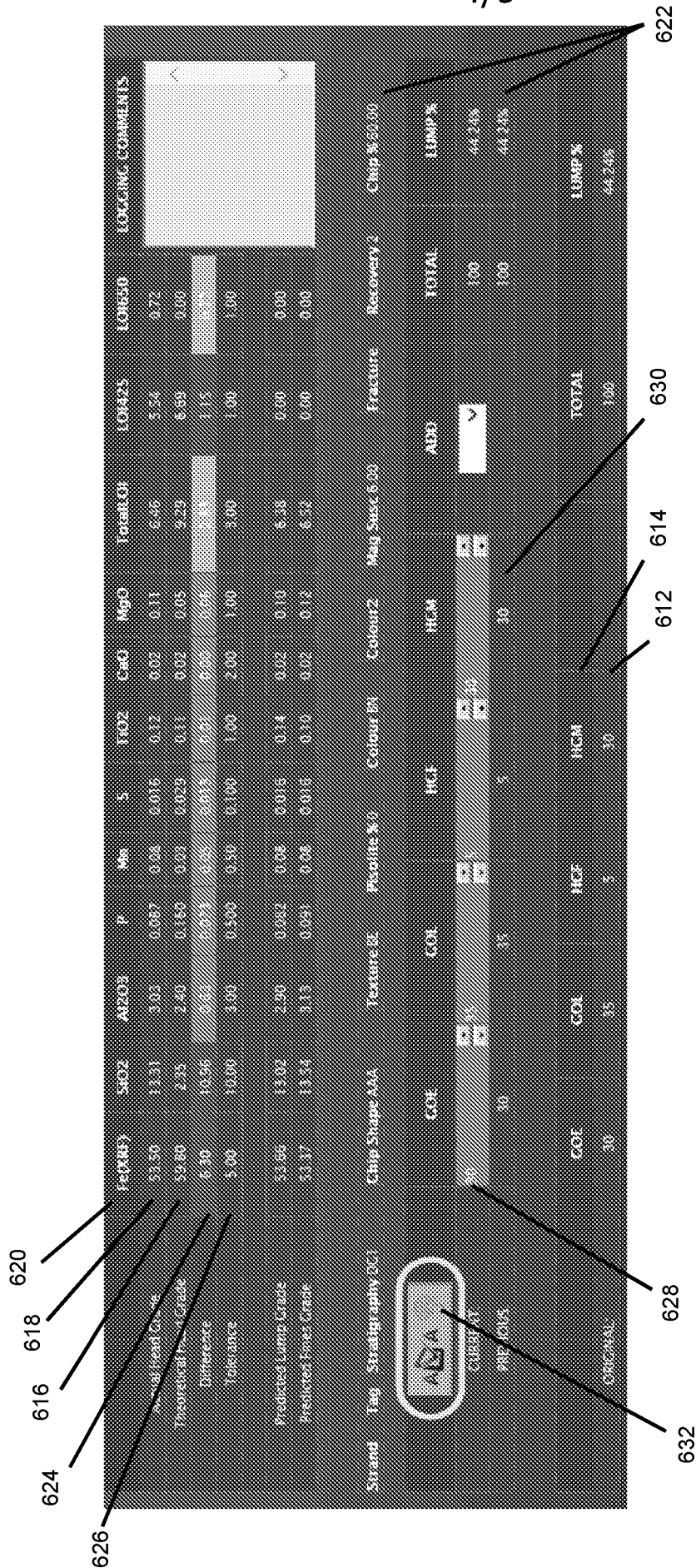


FIGURE 5



## FIGURE 6

714

716

710

712

| Auto Validation Results |     |     |     |     |     |     |     |     |     |     |  |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|
| Confidence              | H2M | SHL | Q1Z | HCF | COL | HGM | GCE | SHF | H2F | BPO |  |
| 7                       | 5   | 3   | 10  | 15  | 20  | 22  | 26  |     |     |     |  |
| 7                       |     | 6   | 7   | 17  | 17  | 26  | 27  |     |     |     |  |
| 7                       |     | 4   | 10  | 15  | 20  | 22  | 26  | 2   |     |     |  |
| 6                       |     | 3   | 10  |     | 26  | 26  | 23  |     | 10  |     |  |
| 6                       |     | 3   |     | 10  |     | 21  | 39  |     |     | 27  |  |
| 6                       |     | 3   | 14  | 37  |     | 6   | 40  |     |     |     |  |
| 6                       | 7   |     | 9   | 13  | 27  | 11  | 24  | 9   |     |     |  |
| 6                       | 13  | 4   | 9   |     | 32  | 15  | 23  |     | 4   |     |  |
| 6                       |     | 3   |     | 2   | 10  | 27  | 32  |     |     | 26  |  |
| 6                       |     | 3   |     | 3   | 6   | 24  | 35  |     | 2   | 27  |  |
| ASSET                   |     |     |     |     |     |     |     |     |     |     |  |

718

FIGURE 7



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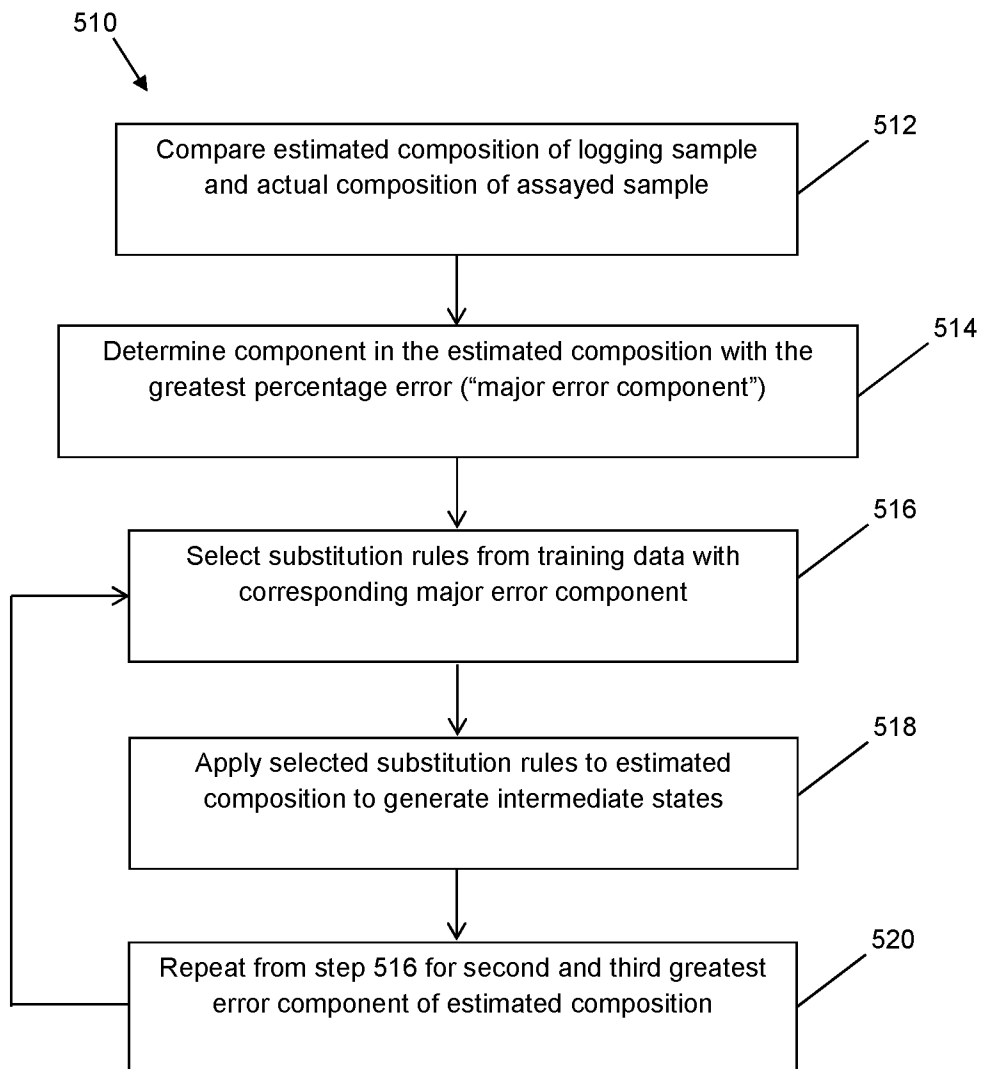


FIGURE 9

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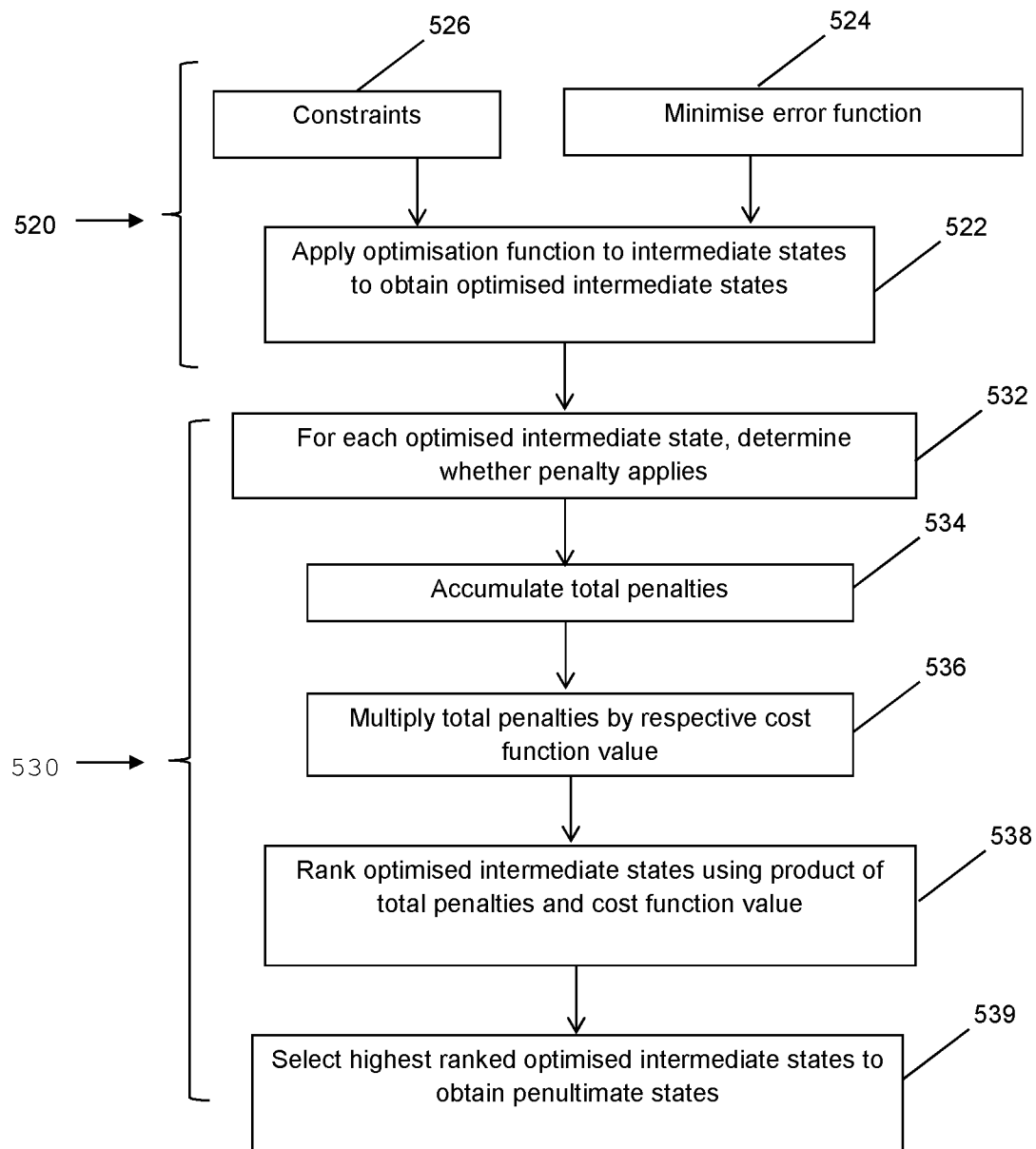


FIGURE 10

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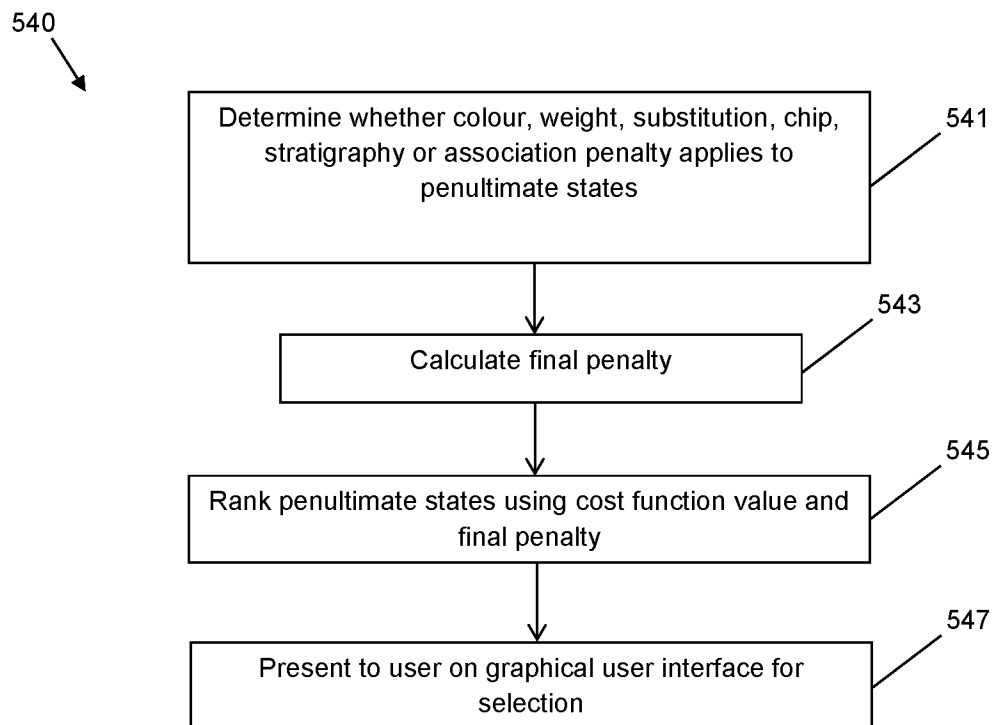


FIGURE 11

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2018/050046

## A. CLASSIFICATION OF SUBJECT MATTER

**G01N 33/24 (2006.01) G01V 9/00 (2006.01) G01V 11/00 (2006.01) G06Q 50/02 (2012.01) E21B 47/00 (2012.01)**  
**E21B 49/00 (2006.01) E21C 39/00 (2006.01)**

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**EPODOC, WPIAP, WPI and INSPEC:** IPC: G06Q50/02, G01V9-, G01V11-, G01V99-, G01N33/24-, E21B47-, E21B49-, E21C39- CPC: G06Q50/02, G01V9-, G01V11-, G01V99-, G01N33/24-, E21B47-, E21B49-, E21C39- Keywords: validate, log, data, sample, mineral, estimate, theoretical, assay, actual, compare, difference, adjust, rule, iterative, multiple, intermediate, penultimate, state, rank, order, select, penalty, error, tolerance and similar terms.

**Google and Google Patents Search:** Keywords as above.**Applicant(s) and/or Inventor(s) Name Search:** AUSPAT, Espacenet, and internal databases provided by IP Australia.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
|           | Documents are listed in the continuation of Box C                                  |                       |



Further documents are listed in the continuation of Box C



See patent family annex

|                                                                                                                                                         |                                                                                                                                                                     |                                                                                                                                          |                                                                                                                                                                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| *<br>"A"                                                                                                                                                | Special categories of cited documents:<br>document defining the general state of the art which is not considered to be of particular relevance                      | "T"                                                                                                                                      | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention                                              |
| "E"                                                                                                                                                     | earlier application or patent but published on or after the international filing date                                                                               | "X"                                                                                                                                      | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone                                                                     |
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| "O"                                                                                                                                                     | document referring to an oral disclosure, use, exhibition or other means                                                                                            | "&"                                                                                                                                      | document member of the same patent family                                                                                                                                                                                                    |
| "P"                                                                                                                                                     | document published prior to the international filing date but later than the priority date claimed                                                                  |                                                                                                                                          |                                                                                                                                                                                                                                              |
| Date of the actual completion of the international search<br>19 March 2018                                                                              |                                                                                                                                                                     | Date of mailing of the international search report<br>19 March 2018                                                                      |                                                                                                                                                                                                                                              |
| Name and mailing address of the ISA/AU<br><br>AUSTRALIAN PATENT OFFICE<br>PO BOX 200, WODEN ACT 2606, AUSTRALIA<br>Email address: pct@ipaustalia.gov.au |                                                                                                                                                                     | Authorised officer<br><br>Greg Maloney<br>AUSTRALIAN PATENT OFFICE<br>(ISO 9001 Quality Certified Service)<br>Telephone No. +61262256165 |                                                                                                                                                                                                                                              |

| INTERNATIONAL SEARCH REPORT                           |                                                                                                                                                                                                                                                | International application No. |
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| X                                                     | US 2016/0033676 A1 (TECHNICAL RESOURCES PTY LTD et al.) 04 February 2016<br>See the entire document, in particular abstract, figures 2 - 5 and 6a - 6c, paragraphs 75 - 77, 81, 85, 89 - 91 and 99.                                            | 35                            |
| Y                                                     | See the entire document, in particular abstract, figures 2 - 5 and 6a - 6c, paragraphs 75 - 77, 81, 85, 89 - 91 and 99.                                                                                                                        | 1 - 34                        |
| X                                                     | US 9507047 B1 (DVORKIN et al.) 29 November 2016<br>See the entire document, in particular the abstract, Figures 5 and 9, column 13 line 38 - column 14 line 5, column 16 lines 3 - 7 and column 32 lines 26 - 34.                              | 35                            |
| Y                                                     | See the entire document, in particular the abstract, Figures 5 and 9, column 13 line 38 - column 14 line 5, column 16 lines 3 - 7 and column 32 lines 26 - 34.                                                                                 | 1 - 34                        |
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| A                                                     | US 2013/0253837 A1 (SAUDI ARABIAN OIL COMPANY) 26 September 2013<br>See the entire document.                                                                                                                                                   | 1 - 35                        |
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| INTERNATIONAL SEARCH REPORT                                                                                                                                                                                                                                           |                   | International application No. |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------|------------------|
| Information on patent family members                                                                                                                                                                                                                                  |                   | PCT/AU2018/050046             |                  |
| This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information. |                   |                               |                  |
| Patent Document/s Cited in Search Report                                                                                                                                                                                                                              |                   | Patent Family Member/s        |                  |
| Publication Number                                                                                                                                                                                                                                                    | Publication Date  | Publication Number            | Publication Date |
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| Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.<br>Form PCT/ISA/210 (Family Annex)(July 2009)                                                                                               |                   |                               |                  |