A method of assaying and/or recovering at least one precious metal from an ore, concentrate or slag containing metal oxide includes mixing crushed ore, concentrate or slag with aluminum and lime and heating the mixture to initiate an aluminothermic reaction at a temperature above its melting point to reduce the metal oxide and produce a metal alloy containing the metal and the precious metal and also produce a slag. The metal alloy containing the precious metal is then separated from the slag.
ABSTRACT OF THIS DISCLOSURE

A method of assaying and/or recovering at least one precious metal from an ore, concentrate or slag containing metal oxide includes mixing crushed ore, concentrate or slag with aluminum and lime and heating the mixture to initiate an aluminothermic reaction at a temperature above its melting point to reduce the metal oxide and produce a metal alloy containing the metal and the precious metal and also produce a slag. The metal alloy containing the precious metal is then separated from the slag.
ASSAYING AND/OR RECOVERING PRECIOUS METALS

FIELD OF THE INVENTION

This invention relates to the assaying and recovery of precious metals from ores, concentrates or slag.

In this application, precious metals include platinum, palladium, gold, rhodium, ruthenium, silver and osmium. The types of ores, concentrates and slags which are most usefully treated by the method of the present invention are those in which precious metals are found in sulfidic, oxidic, ferritic or siliceous states.

Ores in which precious metals are hosted in simple associations with silica can be accurately assayed for precious metal content by standard fire assay techniques using a standard flux containing (among other things) litharge (lead oxide). The ore is smelted and the precious metals are collected by the litharge to produce a lead button which settles at the bottom of the furnace pot, with a barren slag phase being formed on top thereof. The lead button is recovered, roasted, treated with acids to remove the lead and then assayed.

Refractory or otherwise difficult ores contain some elements or minerals, such as sulphides, arsenic, carbon, lead and antimony, which prevent lead or any other collector from fully recovering precious metal. This is well described in U.S. Patent 5,238,485 (Shubert) which explains fire assay practice and why it is difficult to treat different types of ores and concentrates for precious metal assay and therefore recovery. Shubert describes a method for the assay and recovery of precious metals wherein complex ores of the precious metals which also contain iron spinels and similar compounds are assayed and their precious metal content extracted by subjecting the ores or concentrates thereof together with an iron-
embrittling agent to a pyrometallurgical process which reduces at least a major portion of the iron compounds to liquid metallic iron. The liquid iron serves as a collector for the precious metals. After cooling, the iron is brittle and easily comminuted and can be separated from the precious metals through use of either an electrolytic process or selective chemical dissolution of the iron or other base metal leaving the precious metals available for analysis and recovery.

U.S. Patent 5,439,503 (Burr) describes a method for treating iron-bearing igneous rock for the recovery of gold, silver and platinum group metal values contained in such rock by mixing with a suitable flux and metallic copper, and smelting the mixture at a sufficiently high temperature to produce a molten mass of metal containing iron and copper and a molten slag. The molten slag is separated from the molten metal mass in some suitable manner. The slag is discarded and the metal mixture is cooled to a solid state. The copper and iron are then dissolved in acid, leaving an undissolved portion which can then be separated from the resulting leach liquor by filtration.

Alternatively, the iron and copper bearing metal can be cast into an anode and electrolyzed in a sulfuric acid solution where copper is deposited at the cathode and iron is put into solution as iron sulfate. The insoluble residue at the anode can be recovered from the sulfuric acid solution by filtration. The filtered solids from either acid dissolution or electrolysis contain a significant amount of the gold, silver and platinum group metals which were present in the original rock. The solids can then be processed by known technology to recover their gold, silver and platinum group metal content in essentially pure form. The
solution, which contains most of the silver, can be treated in a conventional manner to recover the silver. With electrolysis, copper is recovered as cathode deposit. With acid dissolution, copper can be recovered in known manner. With either, copper can be recycled to the process.

U.S. Patent 4,188,362 (Edwards et al) describes a process for the treatment of platinum group metals and gold wherein a concentrate is caused to alloy with aluminum and the alloy is then leached in at least two steps, the first of which is to remove base metals and in a second of which the precious metals are dissolved using hydrochloric acid and chlorine gas or nitric acid as an oxidant.

U.S. Patent 5,865,872 (Krochak et al) describes a method of recovering metals and producing a secondary slag from base metal smelter slag produced by a copper or nickel smelter including mixing the smelter slag with at least one reducing agent selected from the group consisting of carbon, calcium carbide, ferro silicon and aluminum, the carbon and calcium carbide (if present) being from about 1% to about 40% by weight of the slag and the aluminum (if present) being from about 2% to about 35% by weight of the slag, heating the mixture aluminothermically if aluminum is present as reducing agent above the melting point to reduce the smelter slag to a metal alloy containing iron and possibly silicon and aluminum, depending on the quantity of aluminum added to the smelter slag, and heavy metal such as copper, nickel and cobalt which were in the smelter slag and thereby also producing a secondary slag containing at least one compound from the group consisting of calcium silicate, calcium aluminate, fused alumina and calcium iron aluminum silicate, and separating
the metal alloy from the secondary slag.

It is an object of the present invention to provide an improved method of assaying and/or recovering precious metals from ores, concentrates or slags containing metal oxide and at least one precious metal.

SUMMARY OF THE INVENTION

According to the invention, a method of assaying and/or recovering at least one precious metal from an ore concentrate or slag containing metal oxide and at least one precious metal includes mixing crushed ore, concentrate or slag with aluminum and lime and heating the mixture to initiate an aluminothermic reaction at a temperature above its melting point to reduce the metal oxide and produce a metal alloy containing metal and said at least one precious metal and also produce a slag, and separating the metal alloy containing said at least one precious from the slag.

The metal oxide may comprise iron oxide. A metal oxide may be added to the ore concentrate or slag before heating to increase the metal content to an amount sufficient to enable the aluminothermic reaction to be initiated. The added metal oxide may be iron oxide, copper oxide or mixtures thereof. The aluminum and lime are preferably provided in a ratio in the range of from about 1:1 to about 1:3 by weight, more preferably about 1:2 by weight.

Aluminum is a powerful reducing agent which reacts vigorously with oxygen compounds at high temperatures. If a metal oxide such as ferric or chromic oxide, is mixed
with aluminum powder and the mixture is placed in a suitable crucible and ignited, a violent reaction occurs with the temperature rising to produce a white heat. The metal is liberated and sinks to the bottom of the crucible, and the aluminum oxide simultaneously produced, fuses and then solidifies as an upper layer of hard slag. With ferric oxide, the reaction is as follows:

\[ \text{Fe}_2\text{O}_3 + 2\text{Al} = \text{Al}_2\text{O}_3 + 2\text{Fe} \]

Such a process is also used in the manufacture of chromium, manganese and tungsten.

A mixture of aluminum powder and iron oxide together with some steel in the form of turnings or punchings (known as thermite), when fired in the manner described above, produces liquid steel at a temperature of about 2,500° C. This is used for welding machine parts, etc. in situ, see Sherwood Taylor, pages 393, 394, "Inorganic and Theoretical Chemistry", 1961.

An advantage of aluminothermic reduction is the rapidity of the reaction and the ability at the same time to achieve high temperature compared to conventional reduction processes, for example with carbon. When lime is added, the slag is highly fluid, thereby facilitating separation of the slag from the metal alloy.

DESCRIPTION OF PREFERRED EMBODIMENTS

In order to obtain the best recovery of precious metals (higher concentration and efficiency) at lower cost, the minimum amount of aluminum to reduce enough metal oxide to produce a metal alloy containing the precious metals should be used. If the ore
concentrate or slag contains one or more valuable metals, other than precious metals, as metal oxides, the stoichiometric amount of aluminum should be more than sufficient to reduce the valuable metal as metal alloy together with the precious metal content.

In some cases, such as sulfide ores, where the amount of metal oxide is not sufficient to create a metal alloy aluminothermically, a metal oxide such as iron oxide or copper oxide or both can be added to react with aluminum and lime and function as a collector after the aluminothermic reduction.

The metal alloy obtained can be treated by either electrolysis or dissolution to separately recover the metal and the precious metals. Where the ore concentrate or slag contains iron oxide and silica, the slag may be in the form of a black glass resembling the volcanic glass obsidian which can be used in the concrete industry as a supplementary cementing material, see U.S. Patent 5,865,872 (Kroshchak et al).

Examples of the invention will now be described.

EXAMPLE I

A composite sample of a base metal smelter slag was obtained from Sudbury, Ontario, Canada. The slag was a fayalite type slag with the general chemical formula FeO·SiO₂. The iron is not only present as ferrous oxide but ferric oxide. Because of the affinity of the precious metals for the ferric iron (magnetite and hematite), see U.S. Patent 5,238,485 (Shubert), some of the precious metals contained in the original ore will have reported to the slag as is shown in the following table which indicates precious metal content in percentage.
by weight:

<table>
<thead>
<tr>
<th></th>
<th>Silver</th>
<th>Gold</th>
<th>Platinum</th>
<th>Palladium</th>
<th>Rhodium</th>
<th>Ruthenium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelter Slag</td>
<td>0.0150</td>
<td>0.0068</td>
<td>0.0224</td>
<td>0.0164</td>
<td>0.0253</td>
<td>0.0181</td>
</tr>
</tbody>
</table>

There is no known commercially useful method to recover precious metals from such slag.

In accordance with the invention, 100 grams of base metal smelter slag was mixed in a crucible, lined with alumina to avoid contamination, with 10 grams of aluminum granules and 20 grams of lime chips and heated in a propane heated furnace, with the charge therefore being as follows:

<table>
<thead>
<tr>
<th>Charge</th>
<th>Weight in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Metal Smelter Slag</td>
<td>100</td>
</tr>
<tr>
<td>Aluminum Powder</td>
<td>10</td>
</tr>
<tr>
<td>Lime Chips</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
</tr>
</tbody>
</table>

The crucible was heated until an aluminothermic reaction was initiated. The temperature rose to greater than 2,500° C, producing a white heat and causing the charge to melt and drop the metal alloy to the bottom. This was completed in 15 minutes. After one
hour cooling, the sample was removed from the furnace, and the metal alloy was easily separated from the secondary slag. The metal alloy and secondary slag were separately weighed, as follows:

<table>
<thead>
<tr>
<th>Charge</th>
<th>Weight in Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Slag (Black Glass)</td>
<td>105</td>
</tr>
<tr>
<td>Metal Alloy</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
</tr>
</tbody>
</table>

Both the new slag and the metal alloy were analyzed for precious metals with the following results, the precious metal content being shown in percentage by weight:

<table>
<thead>
<tr>
<th></th>
<th>Silver</th>
<th>Gold</th>
<th>Platinum</th>
<th>Palladium</th>
<th>Rhodium</th>
<th>Ruthenium</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Slag</td>
<td>0.0020</td>
<td>0.0003</td>
<td>0.0010</td>
<td>0.0006</td>
<td>0.0011</td>
<td>0.0008</td>
</tr>
<tr>
<td>Metal Alloy</td>
<td>0.0130</td>
<td>0.0065</td>
<td>0.0214</td>
<td>0.0158</td>
<td>0.0242</td>
<td>0.0173</td>
</tr>
</tbody>
</table>

The metal alloy, which is mainly an iron alloy, can be treated by convention dissolution or electrolytic methods to recover the precious metals.

EXAMPLE 2

A composite sample of bentonite black shale with up to 30% iron sulphide species was obtained from Alberta, Canada. The shale was a typical refractory ore which was difficult to analyze. The sample was analyzed for gold with Fire Assay (FA) and instrumental Neutron Activation Analysis (INAA) with the following results:
FA | INAA
---|---
Gold in parts per billion | 4 | 6

The sample was treated with a proprietary process (described in U.S. Patent 6,026,965, Berardi et al) to obtain a concentrate before treating with aluminum and lime. 100 grams of the concentrate was mixed with 10 grams of copper oxide, 10 grams of aluminum granulares and 20 grams of lime chips. The charge was treated as an example 1.

The resultant metal alloy (copper and iron alloy) was analyzed for gold through Fire Assay (FA) with the following result:

FA
Gold in parts per million 15.1

Again, the copper/iron alloy can be treated by dissolution or electrolytic methods to recover the gold.

It is apparent that the present invention can be successfully utilized for precious metal recovery, particularly with those ores, concentrates or slags that are difficult to assay.

Other embodiments and examples of the invention will now be readily apparent to a person skilled in the art from the foregoing description, the scope of the invention being defined in the appended claims.
CLAIMS

1. A method of assaying and/or recovering at least one precious metal from an ore, concentrate or slag containing metal oxide and at least one precious metal, including mixing crushed ore, concentrate or slag with aluminum and lime and heating the mixture to initiate an aluminothermic reaction at a temperature above its melting point to reduce the metal oxide and produce a metal alloy containing the metal and said at least one precious metal and also produce a slag, and separating the metal alloy containing said at least one precious metal from the slag.

2. A method according to claim 1 wherein said metal oxide comprises iron oxide.

3. A method according to claim 1 wherein a metal oxide is added to the ore concentrate or slag before said heating to increase the metal content of the mixture to an amount sufficient to enable an aluminothermic reaction to be initiated.

4. A method according to claim 3 wherein said added metal oxide is selected from the group consisting of an oxide, copper oxide and mixtures thereof.

5. A method according to claim 1 wherein said aluminum and lime are provided in a ratio in the range of from about 1:1 to about 1:3 by weight.
6. A method according to claim 5 wherein said aluminum and lime are provided in a ratio of about 1:2 by weight.