In one embodiment of the first or second aspects, the titanium-bearing material comprising perovskite is chosen from the group consisting of slag, an ore, upgraded slag, and a concentrate. In one particular embodiment, the titanium-bearing material comprising perovskite is an iron making slag. In one embodiment, the iron making slag is melter slag or blast furnace slag. In another embodiment, the ore is a vanadium titano-magnetite ore. In another embodiment, the slag is a vanadium titano-magnetite slag. In other embodiments, the titanium-bearing material comprising perovskite comprises a combination of two or more different sources of titanium-bearing material.

In particular embodiments, the titanium-bearing material is in the form of a particulate material having an average particle size of less than 180µm. In preferred embodiments, the particulate material has an average particle size from 10 to 180µm, or from 40 to 110 µm. In particular embodiments, the particulate material has an average particle size of approximately 30µm, 45µm, 60µm, 70µm, 80µm, 90µm, or 100µm.

In certain embodiments, the method of the invention further comprises the step of grinding the titanium-bearing material prior to step a) of the process of the first to fourth aspects.

In one embodiment of the first or second aspects, the titanium-bearing material is contacted with sulfuric acid in a continuous reactor. In one embodiment, the sulfation step b) takes place in a continuous reactor adapted for continuous blending of the sulfuric acid, titanium-bearing material and cake comprising titanyl sulfate.

In a preferred embodiment, one or more additional steps of the methods of the first or second aspects of the invention are conducted in a continuous manner. In a preferred embodiment of the first to fourth aspects, the whole method is conducted in a continuous manner.

In a third aspect, the invention provides one or more products produced by a method of the first or second aspects of the invention, the one or more product chosen from the group consisting of: titanium dioxide, magnesium sulphate, the first retentate, calcium sulphate, silica, aluminium sulphate, mixed metal solids.

In certain embodiments, the magnesium sulphate is in the form of MgSO4.7H20, MgSO4.6H2O or MgSO4.1H2O. In certain embodiments, the aluminium sulphate is in the form of Al2(SO4)3.XH2O, where X is 14 to 18. In certain embodiments, the calcium sulphate is in the form of CaSO4.2H20.

CLAIMS

1. A method for the recovery of one or more product from a titanium-bearing material comprising perovskite, the method comprising:

(a) contacting the titanium-bearing material with sulfuric acid to form a cake comprising at least titanyl sulfate;

(b) contacting the cake with water and/or dilute sulfuric acid to form a sulfated suspension comprising at least titanyl sulfate;

(c) separating solids from liquid in the sulfated suspension to produce a first permeate comprising at least titanyl sulfate and a first retentate comprising at least calcium sulfate and silica;

(d) hydrolysing titanyl sulphate in the first permeate to produce a first liquor comprising titanium dioxide hydrate;

(e) separating titanium dioxide hydrate from the first liquor to produce titanium dioxide hydrate and a second liquor comprising at least aluminium sulfate; and

(f) separating aluminium sulfate from the second liquor to produce aluminium sulfate and a third liquor comprising mixed metal sulfates.

2. A method for the recovery of one or more product from a titanium-bearing material comprising perovskite, the method comprising:

(a) contacting the titanium-bearing material with sulfuric acid to form a cake comprising at least titanyl sulfate;

(b) contacting the cake with water and/or dilute sulfuric acid to form a sulfated suspension comprising at least titanyl sulfate;

(c) separating solids from liquid in the sulfated suspension to produce a first permeate comprising at least titanyl sulfate and a first retentate comprising at least calcium sulfate and silica;

(d) separating aluminium sulfate from the first permeate to produce aluminium sulfate and a first liquor comprising at least titanyl sulfate;

(e) hydrolysing titanyl sulphate in the first liquor to produce a second liquor comprising titanium dioxide hydrate; and

(f) separating titanium dioxide hydrate from the second liquor to produce titanium dioxide hydrate and a third liquor comprising mixed metal sulfates.

3. A method according to Claim 1 or 2, further comprising the step of:

(g) combining calcium carbonate and the third liquor to produce a first composition which comprises mixed metal sulfates comprising calcium sulfate.

4. A method as claimed in claim 3, the method further comprising the step of:

(h) separating calcium sulfate from the first composition to produce calcium sulfate and a fourth liquor comprising mixed metal sulfates.

5. A method according to Claim 4, further comprising the step of:

(i) separating magnesium sulfate from the fourth liquor to produce magnesium sulfate and a fifth liquor comprising mixed metal sulfates.

6. A method according to Claim 5, further comprising the step of:

(j) combining calcium hydroxide and the fifth liquor to produce a second composition which comprises mixed metal hydroxides and/or oxides and calcium sulphate, or combining magnesium hydroxide and the fifth liquor to produce a second composition which comprises mixed metal hydroxides and/or oxides.

7. A method according to Claim 6, the method further comprising the step of:

(k) Recovering the mixed metal oxides and/or hydroxides or the mixed metal oxides and/or hydroxides and calcium sulphate from the second composition to produce mixed metal solids.

8. A method according to Claim 4, the method further comprising the step of:

(i) combining calcium hydroxide and the fourth liquor to produce a second composition comprising mixed metal oxides and/or hydroxides, calcium sulphate and magnesium sulphate or combining magnesium hydroxide and the fourth liquor to produce a second composition comprising mixed metal oxides and/or hydroxides and magnesium sulphate.

9. A method according to Claim 8, the method further comprising the step of:

(j) separating the mixed metal oxides and/or hydroxides or the mixed metal oxides and/or hydroxides and calcium sulphate from the second composition to produce mixed metal solids or mixed metal solids and calcium sulphate and a fifth liquor comprising magnesium sulfate.

10. A method according to Claim 9, the method further comprising the step of:

(k) recovering magnesium sulfate from the fifth liquor to produce magnesium sulfate.

11. A method according to any one Claims 3 to 10, in which calcium carbonate is combined with the third liquor so that the pH is in the range of from approximately 1 to approximately 4.

12. A method according to in any of Claims 6 to 11, in which calcium hydroxide or magnesium hydroxide is combined with the fifth liquor so that the pH is in the range of from approximately 7 to approximately 10.

13. A method according to any of Claims 3 to 12, in which step (g) is conducted under conditions in which titanium present is in the form of Ti^{4+} and iron present is in the form of Fe^{2+} to produce a first composition comprising calcium sulfate and one or more titanium oxides and/or hydroxides and then optionally separating calcium sulfate and one or more titanium oxides and/or hydroxides from the first composition to produce calcium sulfate and one or more titanium oxides and/or hydroxides and a fourth liquor comprising mixed metal sulfates.

14. A method according to Claim 13, in which the ORP is in the range of from approximately 200mV to approximately 300mV.

15. A method according to any preceding claim, in which the method further comprises the step of calcining the hydrated titanium dioxide to produce titanium dioxide.

16. A method according to any preceding claim, in which the titanium-bearing material comprising perovskite is chosen from the group comprising: a slag, an ore, an upgraded slag, a concentrate and combinations of two or more thereof.

17. A method according to Claim 16, in which the titanium-bearing material is chosen from the group comprising: an iron making slag, melter slag, blast furnace slag, a vanadium titano-magnetite ore, a vanadium titano-magnetite slag or combinations of two or more thereof.

18. A method according to any preceding claim, in which the titanium-bearing material is contacted with sulfuric acid in a ratio from approximately 0.75:1 to approximately 2:1.

19. A method according to any preceding claim, in which step (a) is conducted so that the combined titanium-bearing material and sulfuric acid reaches a temperature of from approximately 130 degrees C to approximately 250 degrees C.

20. A method according to any preceding claim, in which the concentration of sulfuric acid used is from at least approximately 60%.

21. A method according to any preceding claim, in which step (a) is conducted for a period of from approximately 30 minutes to approximately 4 hours.

22. A method according to any preceding claim, in which the one or more product is chosen from the group comprising: titanium dioxide, aluminium sulfate, calcium sulfate, silica, magnesium sulfate, mixed metal solids, and the first retentate.

23. A method for producing a titanium dioxide feedstock for a titanium dioxide pigment manufacturing process, in which the method comprises the steps as claimed in any of Claims 1 to 21.

24. A method for the recovery of one or more product from a composition derived from a sulfate process for the production or recovery of titanium dioxide, the method comprising at least the steps of:

(a) combining calcium carbonate and the composition to produce a composition (A) which comprises calcium sulphate; and,

(b) separating calcium sulfate from the composition (A) to produce calcium sulfate and a composition (B) comprising mixed metal sulfates comprising magnesium sulfate,

in which the composition derived from a sulfate process for the production or recovery of titanium dioxide is an acidic composition produced or recovered after recovery of titanium dioxide.

25. A method according to Claim 24, in which the composition derived from a sulfate process for the production or recovery of titanium dioxide is treated or processed prior to step (a).

26. A method according to Claim 24 or 25, the method further comprising the step of:

(c) separating magnesium sulfate from composition (B) to produce magnesium sulfate and a composition (C) comprising mixed metal sulfates.

27. A method according to Claim 26, the method further comprising the step of:

(d) combining calcium hydroxide and the composition (C) to produce a composition (D) comprising mixed metal oxides and/or hydroxides and calcium sulphate; OR

(d1) combining magnesium hydroxide with the composition (C) to produce a composition (D) comprising mixed metal oxides and/or hydroxides.

28. A method according to Claim 27, the method further comprising the step of:

(e) recovering the mixed metal oxides and/or hydroxides and calcium sulfate, or the mixed metal oxides and/or hydroxides from the composition (D) to produce mixed metal solids or mixed metal solids comprising calcium sulfate.

29. A method according to Claim 26, the method further comprising the step of:

(c) combining calcium hydroxide with the composition (B) to produce a composition (C') comprising magnesium sulfate, mixed metal oxides and/or hydroxides and calcium sulphate; OR

(c1) combining magnesium hydroxide with the composition (B) to produce a composition (C') comprising magnesium sulfate and mixed metal oxides and/or hydroxides.

30. A method according to Claim 29, the method further comprising the step of:

(d) separating the mixed metal oxides and/or hydroxides and calcium sulfate, or the mixed metal oxides and/or hydroxides from the composition (C') to produce mixed metal solids comprising calcium sulfate or mixed metal solids and a composition (D') comprising magnesium sulfate.

31. A method according to Claim 30, the method further comprising the step of:

(e) recovering magnesium sulfate from composition (D') to produce magnesium sulfate.

32. A method according to any of Claims 24 to 31, in which calcium carbonate is combined with the composition so that the pH is in the range of from approximately 1 to approximately 4.

33. A method according to any of Claims 27 to 32, in which calcium hydroxide or magnesium hydroxide is combined with the composition (B) or composition (C) so that the pH is in the range of from approximately 7 to approximately 10.

34. A method according to any of Claims 24 to 33, in which step (a) is conducted under conditions in which titanium present is in the form of Ti^{4+} and iron present is in the form of Fe^{2+} to produce a composition (A) comprising calcium sulfate, and one or more titanium oxides and/or hydroxides.

35. A method according to Claim 34, in which the ORP is in the range of from approximately 200mV to approximately 300mV.

36. A method according to Claim 34 or 35, in which the method further comprises separating calcium sulfate and one or more titanium oxides and/or hydroxides from composition (A) to produce calcium sulfate and one or more titanium oxides and/or hydroxides and a composition (B) comprising mixed metal sulfates.

In one embodiment of the first or second aspects, the titanium-bearing material comprising perovskite is chosen from the group consisting of slag, an ore, upgraded slag, and a concentrate. In one particular embodiment, the titanium-bearing material comprising perovskite is an iron making slag. In one embodiment, the iron making slag is melter slag or blast furnace slag. In another embodiment, the ore is a vanadium titano-magnetite ore. In another embodiment, the slag is a vanadium titano-magnetite slag. In other embodiments, the titanium-bearing material comprising perovskite comprises a combination of two or more different sources of titanium-bearing material.

In particular embodiments, the titanium-bearing material is in the form of a particulate material having an average particle size of less than 180µm. In preferred embodiments, the particulate material has an average particle size from 10 to 180µm, or from 40 to 110 µm. In particular embodiments, the particulate material has an average particle size of approximately 30µm, 45µm, 60µm, 70µm, 80µm, 90µm, or 100µm.

In certain embodiments, the method of the invention further comprises the step of grinding the titanium-bearing material prior to step a) of the process of the first to fourth aspects.

In one embodiment of the first or second aspects, the titanium-bearing material is contacted with sulfuric acid in a continuous reactor. In one embodiment, the sulfation step a) takes place in a continuous reactor adapted for continuous blending of the sulfuric acid, titanium-bearing material and cake comprising titanyl sulfate.

In a preferred embodiment, one or more additional steps of the methods of the first or second aspects of the invention are conducted in a continuous manner. In a preferred embodiment of the first to fourth aspects, the whole method is conducted in a continuous manner.

In a third aspect, the invention provides one or more products produced by a method of the first or second aspects of the invention, the one or more product chosen from the group consisting of: titanium dioxide, magnesium sulphate, the first retentate, calcium sulphate, silica, aluminium sulphate, mixed metal solids.

In certain embodiments, the magnesium sulphate is in the form of $MgSO_4.7H_2O$, $MgSO_4.6H_2O$ or $MgSO_4.1H_2O$. In certain embodiments, the aluminium sulphate is in the form of $Al_2(SO_4)_3.XH_2O$, where X is 14 to 18. In certain embodiments, the calcium sulphate is in the form of $CaSO_4.2H_2O$.

CLAIMS

1. A method for the recovery of one or more product from a titanium-bearing material comprising perovskite, the method comprising:

(a) contacting the titanium-bearing material with sulfuric acid to form a cake comprising at least titanyl sulfate;

(b) contacting the cake with water and/or dilute sulfuric acid to form a sulfated suspension comprising at least titanyl sulfate;

(c) separating solids from liquid in the sulfated suspension to produce a first permeate comprising at least titanyl sulfate and a first retentate comprising at least calcium sulfate and silica;

(d) hydrolysing titanyl sulphate in the first permeate to produce a first liquor comprising titanium dioxide hydrate;

(e) separating titanium dioxide hydrate from the first liquor to produce titanium dioxide hydrate and a second liquor comprising at least aluminium sulfate; and

(f) separating aluminium sulfate from the second liquor to produce aluminium sulfate and a third liquor comprising mixed metal sulfates;

in which the titanium-bearing material is contacted with sulfuric acid in a ratio of sulfuric acid to titanium-bearing material of from approximately 0.75:1 to approximately 2:1.

2. A method for the recovery of one or more product from a titanium-bearing material comprising perovskite, the method comprising:

(a) contacting the titanium-bearing material with sulfuric acid to form a cake comprising at least titanyl sulfate;

(b) contacting the cake with water and/or dilute sulfuric acid to form a sulfated suspension comprising at least titanyl sulfate;

(c) separating solids from liquid in the sulfated suspension to produce a first permeate comprising at least titanyl sulfate and a first retentate comprising at least calcium sulfate and silica;

(d) separating aluminium sulfate from the first permeate to produce aluminium sulfate and a first liquor comprising at least titanyl sulfate;

(e) hydrolysing titanyl sulphate in the first liquor to produce a second liquor comprising titanium dioxide hydrate; and

(f) separating titanium dioxide hydrate from the second liquor to produce titanium dioxide hydrate and a third liquor comprising mixed metal sulfates;

in which the titanium-bearing material is contacted with sulfuric acid in a ratio of sulfuric acid to titanium-bearing material of from approximately 0.75:1 to approximately 2:1.

3. A method according to Claim 1 or 2, further comprising the step of:

(g) combining calcium carbonate and the third liquor to produce a first composition which comprises mixed metal sulfates comprising calcium sulfate.

4. A method according to Claim 3, the method further comprising the step of:

(h) separating calcium sulfate from the first composition to produce calcium sulfate and a fourth liquor comprising mixed metal sulfates.

5. A method according to Claim 4, further comprising the step of:

(i) separating magnesium sulfate from the fourth liquor to produce magnesium sulfate and a fifth liquor comprising mixed metal sulfates.

6. A method according to Claim 5, further comprising the step of:

(j) combining calcium hydroxide and the fifth liquor to produce a second composition which comprises mixed metal hydroxides and/or oxides and calcium sulphate, or combining magnesium hydroxide and the fifth liquor to produce a second composition which comprises mixed metal hydroxides and/or oxides.

7. A method according to Claim 6, the method further comprising the step of:

(k) recovering the mixed metal oxides and/or hydroxides or the mixed metal oxides and/or hydroxides and calcium sulphate from the second composition to produce mixed metal solids.

8. A method according to Claim 4, the method further comprising the step of:

(i) combining calcium hydroxide and the fourth liquor to produce a second composition comprising mixed metal oxides and/or hydroxides, calcium sulphate and magnesium sulphate or combining magnesium hydroxide and the fourth liquor to produce a second composition comprising mixed metal oxides and/or hydroxides and magnesium sulphate.

9. A method according to Claim 8, the method further comprising the step of:

(j) separating the mixed metal oxides and/or hydroxides or the mixed metal oxides and/or hydroxides and calcium sulphate from the second composition to produce mixed metal solids or mixed metal solids and calcium sulphate and a fifth liquor comprising magnesium sulfate.

10. A method according to Claim 9, the method further comprising the step of:

(k) recovering magnesium sulfate from the fifth liquor to produce magnesium sulfate.

11. A method according to any of Claims 3 to 10, in which calcium carbonate is combined with the third liquor so that the pH is in the range of from approximately 1 to approximately 4.

12. A method according to any of Claims 6 to 11, in which calcium hydroxide or magnesium hydroxide is combined with the fourth or fifth liquor so that the pH is in the range of from approximately 7 to approximately 10.

13. A method according to any of Claims 3 to 12, in which step (g) is conducted under conditions so that titanium present is in the form of Ti^{4+} and iron present is in the form of Fe^{2+} to produce a first composition comprising calcium sulfate and one or more titanium oxides and/or hydroxides and then optionally separating calcium sulfate and one or more titanium oxides and/or hydroxides from the first composition to produce calcium sulfate and one or more titanium oxides and/or hydroxides and a fourth liquor comprising mixed metal sulfates.

14. A method according to Claim 13, in which the ORP is in the range of from approximately 200mV to approximately 300mV.

15. A method according to any preceding claim, in which the method further comprises the step of calcining the hydrated titanium dioxide to produce titanium dioxide.

16. A method according to any preceding claim, in which the titanium-bearing material comprising perovskite is chosen from the group comprising: a slag, an ore, an upgraded slag, a concentrate and combinations of two or more thereof.

17. A method according to Claim 16, in which the titanium-bearing material is chosen from the group comprising: an iron making slag, melter slag, blast furnace slag, a vanadium titano-magnetite ore, a vanadium titano-magnetite slag or combinations of two or more thereof.

18. A method according to any preceding claim, in which step (a) is conducted so that the combined titanium-bearing material and sulfuric acid reaches a temperature of from approximately 130 degrees C to approximately 250 degrees C.

19. A method according to any preceding claim, in which the concentration of sulfuric acid used is from at least approximately 60%.

20. A method according to any preceding claim, in which step (a) is conducted for a period of from approximately 30 minutes to approximately 4 hours.

21. A method according to any preceding claim, in which the one or more product is chosen from the group comprising: titanium dioxide, aluminium sulfate, calcium sulfate, silica, magnesium sulfate, mixed metal solids, and the first retentate.

22. A method for producing a titanium dioxide feedstock for a titanium dioxide pigment manufacturing process, in which the method comprises the steps according to any of Claims 1 to 20.