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(54) Titre : PROCEDE DE FORMATION D'ELEMENTS EN DIAMANT POLYCRISTALLIN, ELEMENTS EN DIAMANT POLYCRISTALLIN, ET OUTILS DE FORAGE DE TERRE PORTANT DE TELS ELEMENTS EN DIAMANT POLYCRISTALLIN

(54) Title: METHODS OF FORMING POLYCRYSTALLINE DIAMOND ELEMENTS, POLYCRYSTALLINE DIAMOND ELEMENTS, AND EARTH-BORING TOOLS CARRYING SUCH POLYCRYSTALLINE DIAMOND ELEMENTS

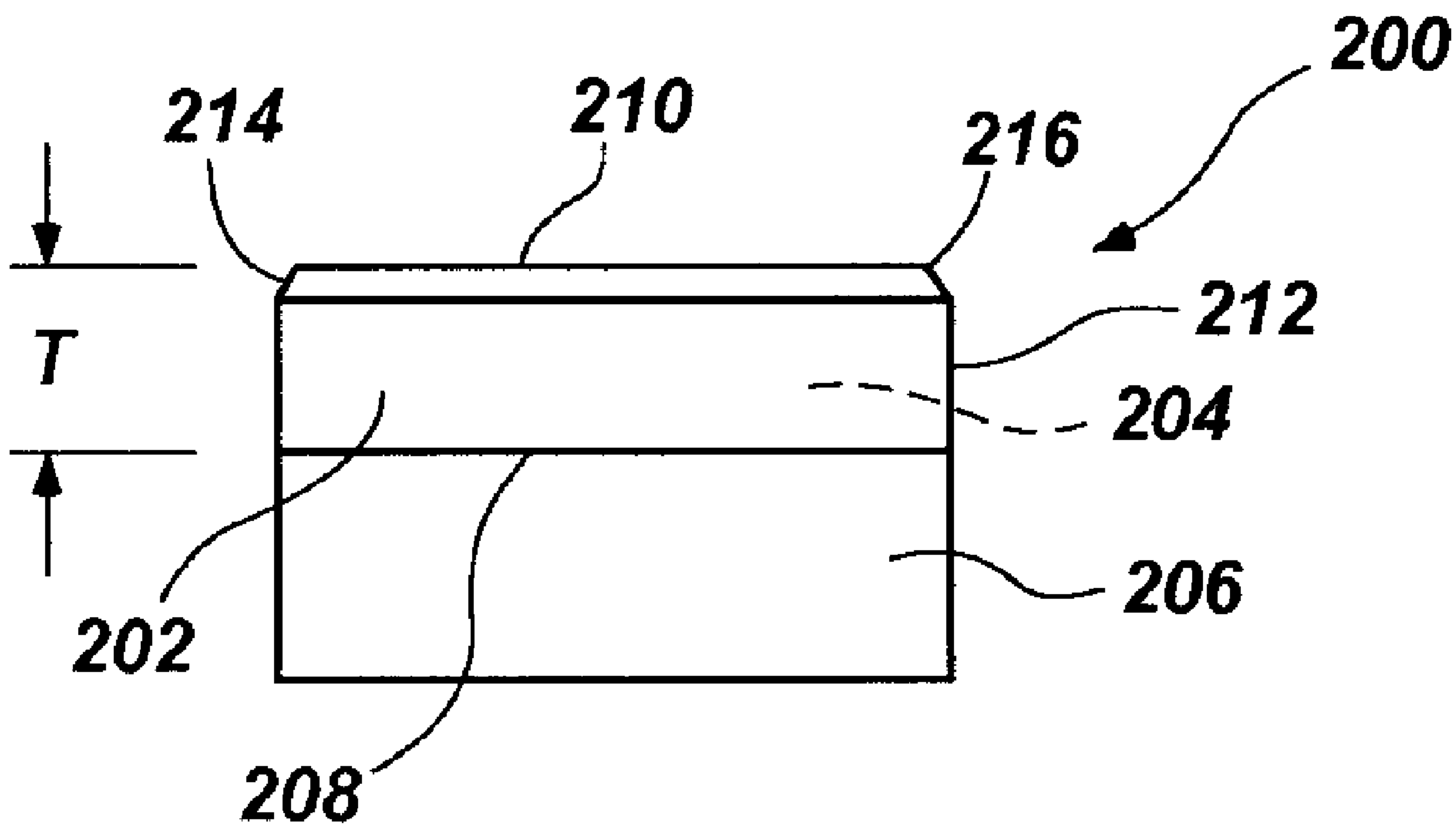

FIG. 2A

(57) Abrégé/Abstract:
Methods of forming polycrystalline diamond elements include forming a polycrystalline diamond element. A Group VIII metal or alloy catalyst is employed to form the polycrystalline diamond compact table at a pressure of at least about 6.5 GPa or greater. The

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(57) Abrégé(suite)/Abstract(continued):

catalyst is then removed from at least a portion of the table to a depth from a working surface thereof, and may be removed from the entirety of the table. Polycrystalline diamond elements include such polycrystalline diamond compact tables. Earth-boring tools include such polycrystalline diamond elements carried thereon and employed as cutting elements.

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(54) **Title**: METHOD OF FORMING POLYSTALLINE DIAMOND ELEMENTS, POLYCRYSTALLINE DIAMOND ELEMENTS, AND EARTH BORING TOOLS CARRYING SUCH POLYCRYSTALLINE DIAMOND ELEMENTS

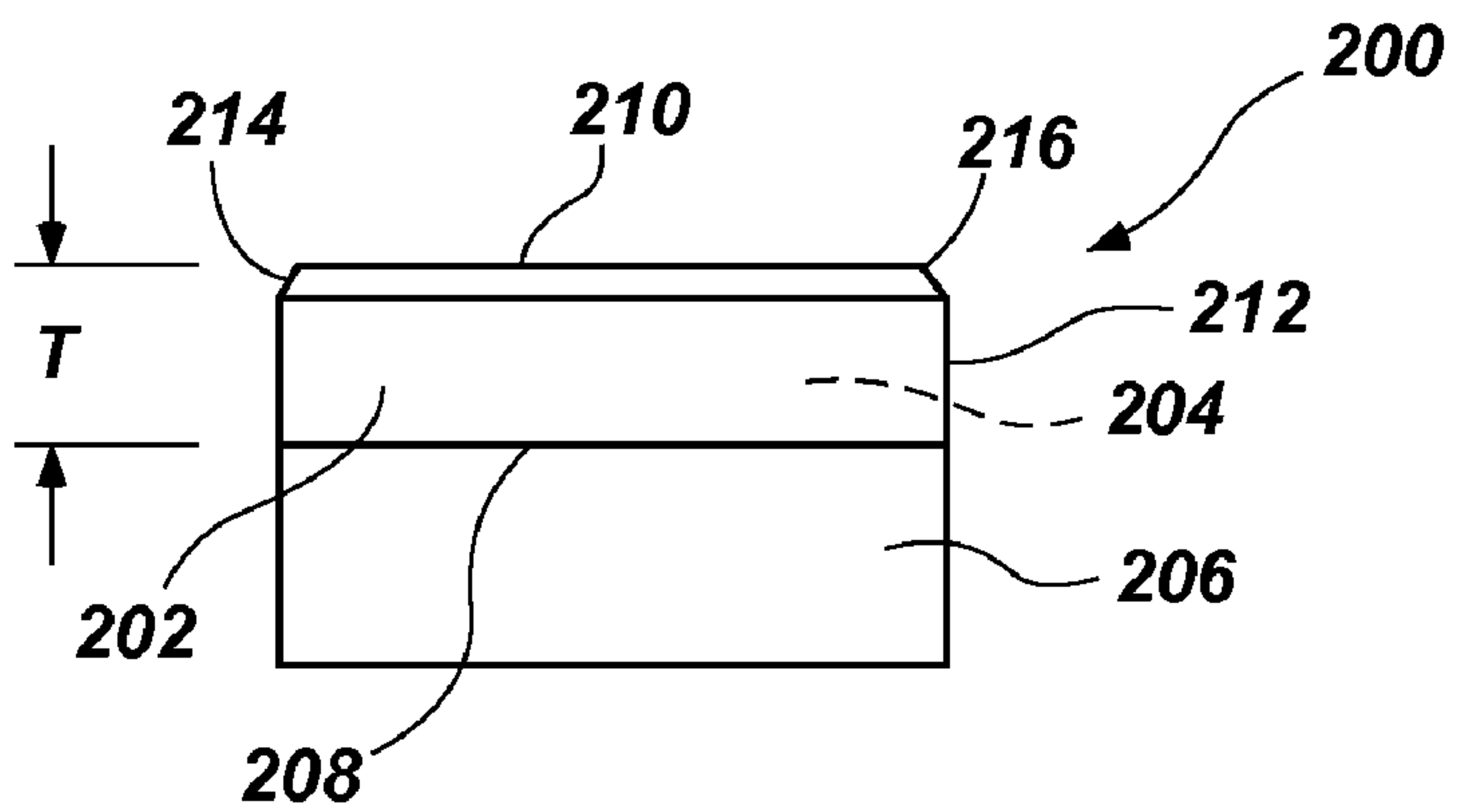

FIG. 2A

(57) **Abstract**: Methods of forming polycrystalline diamond elements include forming a polycrystalline diamond element. A Group VIII metal or alloy catalyst is employed to form the polycrystalline diamond compact table at a pressure of at least about 6.5 GPa or greater. The catalyst is then removed from at least a portion of the table to a depth from a working surface thereof, and may be removed from the entirety of the table. Polycrystalline diamond elements include such polycrystalline diamond compact tables. Earth-boring tools include such polycrystalline diamond elements carried thereon and employed as cutting elements.

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METHODS OF FORMING POLYCRYSTALLINE DIAMOND ELEMENTS, POLYCRYSTALLINE DIAMOND ELEMENTS, AND EARTH-BORING TOOLS CARRYING SUCH POLYCRYSTALLINE DIAMOND ELEMENTS

PRIORITY CLAIM

This application claims the benefit of U.S. Provisional Patent Application Serial No. 61/ 234,776, filed August 18, 2009, for "METHODS OF FORMING POLYCRYSTALLINE DIAMOND ELEMENTS, ELEMENTS SO FORMED, AND EARTH-BORING TOOLS CARRYING SUCH ELEMENTS."

TECHNICAL FIELD

Embodiments of the invention relate to methods of forming polycrystalline diamond elements at ultra high pressure, the polycrystalline diamond elements having enhanced structural integrity and thermal stability, to polycrystalline diamond elements formed at ultra high pressure, and earth-boring tools employing such polycrystalline diamond elements as cutting elements.

BACKGROUND

Superabrasive cutting elements in the form of Polycrystalline Diamond Compact (PDC) structures have been commercially available for almost four decades, and PDC cutting elements having a polycrystalline diamond compact formed on the end of a supporting substrate for a period in excess of thirty years. The latter type of PDC cutting elements commonly comprises a thin, substantially circular disc (although other configurations are available), commonly termed a "table," including a layer of superabrasive material formed of diamond crystals mutually bonded with diamond-to-diamond bonds under ultrahigh temperatures and pressures and defining a front cutting face, a rear face and a peripheral or circumferential edge, at least a portion of which is employed as a cutting edge to cut the subterranean formation being drilled by a drill bit on which the PDC cutting element is mounted.

PDC cutting elements are generally bonded over their rear face during formation of the superabrasive table to a backing layer or substrate formed of cemented tungsten carbide, although self-supporting PDC cutting elements are also known, particularly those stable at higher temperatures, which are known as Thermally Stable Polycrystalline Diamond, or "TSPs," for "thermally stable products." Such cutting elements are widely used on rotary fixed cutter, or "drag," bits, as well as on other bits and tools used to drill and ream subterranean formations, such other bits and tools including without limitation core bits, bi-center bits, eccentric bits, hybrid (*e.g.,* rolling components in combination with fixed cutting elements), roller cone bits, reamer wings, expandable reamers, and casing milling tools. As used herein, the term "drilling tool" encompasses all of the foregoing, and equivalent structures.

In the formation of either type of cutting element, a Group VIII metal catalyst, typically cobalt, is usually employed to stimulate diamond-to-diamond bonding of the diamond crystals. Unfortunately, the presence of a catalyst in the diamond table may lead to thermal degradation commencing at about 400° C due to differences in the coefficients of thermal expansion (CTEs) of the diamond and the catalyst, and commencing around 700-750° C due to stimulation of back-graphitization of the diamond to carbon by the catalyst. Such temperatures may be reached by the cutting edge of a PDC cutting element during drilling of a formation, despite the use of drilling fluid as a cooling agent and despite relatively rapid heat transfer into the diamond table, the substrate, and the body of the drill bit on which the cutting element is mounted.

It has been recognized in the art that removal of the catalyst from the cutting surface of the diamond table, particularly at the cutting edge thereof and along the side of the diamond table proximate the cutting edge and extending toward the substrate, reduces the tendency of those portions of the diamond table to degrade due to thermal effects. It is also known in the art that removal of substantially all of the catalyst from all or a part of the PDC cutting element, such as from a layer adjacent an exposed surface of the PDC cutting element, may result in a physically or structurally weaker portion of the diamond table, which is particularly undesirable in high stress areas, such as proximate a cutting edge of the diamond table. Consequently, provided the depth of removal of the catalyst is sufficient, the life of the diamond table is extended by reduction in thermal damage and wear, but may be compromised in terms of durability as exemplified by impact resistance. The recognition of the aforementioned thermal degradation effects and how and from what portion of the diamond table the catalyst may be beneficially removed is disclosed in, among many other documents, Japanese Patent JP59-219500, as well as in U.S. Patent Nos. 4,224,380, 5,127,923, 6,544,308 and 6,601,662, U.S. Patent Publication Nos. 2006/0060390, 2006/0060391, 2006/0060392, and 2006/0086540, and PCT International Publication Nos. WO 2004/106003, WO 2004/106004, and WO 2005/110648.

There remains a need for a PDC cutting element which exhibits both enhanced thermal stability and wear resistance in combination with improved cutting edge durability for reduced chipping.

DISCLOSURE

Embodiments of the present disclosure relate to methods of forming polycrystalline diamond elements, such as cutting elements suitable for subterranean drilling, exhibiting enhanced structural integrity and thermal stability, resulting cutting elements, and earth-boring tools employing such cutting elements.

Various embodiments of the present disclosure comprise methods of forming a polycrystalline diamond element. According to one or more embodiments of such methods, a polycrystalline diamond compact is formed at a pressure of 6.5GPa or greater, using a catalyst comprising a Group VIII metal, including with limitation an alloy thereof. The polycrystalline diamond compact may be formed on a supporting substrate, or as a free-standing body. The catalyst is at least substantially removed from a portion of the polycrystalline diamond compact and, in some embodiments, is at least substantially removed from the entire polycrystalline diamond compact.

Other embodiments comprise polycrystalline diamond elements, including without limitation PDC cutting elements. At least some embodiments of such PDC cutting elements may comprise a polycrystalline diamond compact table formed at a pressure of 6.5 GPa or greater and including a catalyst comprising a Group VIII metal, including without limitation an alloy thereof. A supporting substrate may be secured to a surface of the diamond table, or the diamond table may be free-standing. In some embodiments, a portion of the diamond table adjacent to at least one exposed surface thereof is substantially free of the catalyst. In other embodiments, the entirety of the diamond table is substantially free of the catalyst. Further embodiments of the present disclosure comprise drilling tools having PDC cutting elements according to embodiments of the present invention mounted thereto.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flow chart of a process to form a polycrystalline diamond compact cutting element according to at least one embodiment of the present disclosure.

FIGS. 2A and 2B depict the formation of a polycrystalline diamond compact cutting element according to at least one embodiment corresponding to the process flow of FIG.1.

FIG. 3 depicts one example of a drilling tool in the form of a rotary drag bit having cutting elements according to an embodiment of the present disclosure mounted thereto.

FIGS. 4 and 4B depict additional embodiments of a polycrystalline diamond compact cutting element according to the present disclosure.

FIGS. 5 and 6 depict results of drilling operations performed on a subterranean formation with a drill bit carrying polycrystalline diamond elements employed as cutting elements in accordance with an embodiment of the present disclosure and with a drill bit carrying conventional cutting elements.

MODE(S) FOR CARRYING OUT THE INVENTION

The illustrations presented herein are, in some instances, not actual views of any particular diamond element, cutting element, or drilling tool, but are merely idealized representations which are employed to describe the present disclosure. Additionally, elements and features common between figures may retain the same or similar numerical designation.

Various embodiments of the present disclosure comprise methods of forming polycrystalline diamond elements, such as cutting elements suitable for subterranean drilling, exhibiting enhanced thermal and mechanical properties, and resulting cutting elements. Process flow of an embodiment of a method of the present invention is illustrated in FIG. 1, and the associated structures formed during the process are illustrated in FIGS. 2A and 2B. Referring to the foregoing drawing figures, in act 100 (FIG. 1), a polycrystalline diamond compact 200 (FIG. 2A) in the form of a diamond table 202 is formed from a mass of diamond particles (*e.g.*, grit) in the presence of a catalyst 204 in a high pressure, high temperature (HPHT) process. Diamond table 202 may be disc-shaped, as is conventional, but is not so limited. As depicted, the diamond table 202 may be formed on a substrate 206 such as, by way of non-limiting example, a cobalt-cemented tungsten carbide substrate, in a conventional process of the type described, by way of non-limiting example, in U.S. Patent No. 3,745,623. As is also conventional, the substrate 206 may be disc- or cylinder-shaped and of the same diameter as the diamond table 202 formed thereon. The interface 208 between the diamond table 202 and the substrate 206 may be planar or non-planar across the abutting surfaces of the diamond table 202 and the substrate 206, the interface topography not being material to implementation of the present invention. That being said, it is contemplated that use of a non-planar interface topography may be beneficial, as known to those of ordinary skill in the art. Alternatively, the diamond table 202 may be formed as a freestanding polycrystalline diamond compact (*e.g.*, without supporting substrate) in a similar conventional process as described, by way of non-limiting example, in U.S. Patent No. 5,127,923.

The diamond table 202 comprises a nominal thickness T, as measured between a cutting face 210 and the interface 208 at the side wall 212 of the diamond table 202. A bevel 214, which is generally characterized by those working in the art as a "chamfer," may be located between the cutting face 210 and the side wall 212 of the diamond table 202. The line of interface between the chamfer 214 and the outer boundary of the cutting face 210 comprises a cutting edge 216 when the polycrystalline diamond compact 200 is in a pristine, unworn condition and is mounted on a tool for drilling or reaming a subterranean formation, such as a rotary fixed-cutter or "drag" bit. The presence of a chamfer at the cutting edge has demonstrated a reduced tendency toward chipping of a diamond table, as has the use of multiple, contiguous chamfers proximate the cutting edge, a radiused or other arcuate transition proximate the cutting edge, and even a combination of chamfers with an intermediate radius. However, such features do not provide ongoing durability once the diamond table has experienced any substantial wear, and some of these features have demonstrated reduced efficiency and a consequential lower rate of penetration (ROP) during initial stages of drilling before a so-called "wear flat" is formed. In contrast, the diamond table 202 of embodiments of the present invention exhibits increased durability throughout the useful life of the polycrystalline diamond compact 200 as a cutting element on a drilling tool.

By way of example and not limitation, the diamond table 202 may comprise a thickness T selected from a range of thicknesses from about 1 mm to about 4 mm. Within that thickness range, a thickness T in the range of about 1.8 mm to about 2.2 mm may be useful for a wide range of applications in subterranean drilling and reaming.

The diamond grit used to form the diamond table 202 may comprise natural diamond, synthetic diamond, or a mixture, and may comprise a mixture of diamond grit of different sizes (sometimes termed a "multi-modal" grit mixture). More specifically, the diamond table 202 may be formed of, and comprise a single layer of diamond grit of a single nominal size, a single layer of diamond grit employing a multi-modal diamond grit mixture, two or more layers of diamond grit with diamond grit within each layer being of a substantially common nominal size, or two or more layers of diamond grit, at least one of the layers comprising a multi-modal diamond grit mixture, all as known to those of ordinary skill in the art. The aforementioned diamond grit mixtures result, after HPHT processing, in a diamond table 202 having a similar diamond grain distribution, the diamond grit having undergone diamond-to-diamond bonding to form a polycrystalline diamond compact table.

It is contemplated that embodiments of the invention may be implemented using, by way of non-limiting example, a tri-modal single layer diamond table of nominal 10 to 12 micron grain (grit) size, referring to grain size in the feedstock used to form the diamond table, a tri-modal single layer diamond table of nominal 6 micron grain size, a bi-layer diamond table having a tri-modal, nominal 10 to 12 micron grain size layer on the cutting face, chamfer, and an adjacent portion of the side wall, and having an underlying quad-modal base layer with a nominal grain size of 18 to 20 microns adjacent to the substrate, or a unimodal, single layer diamond table of nominal 30 micron grain size. In other embodiments, the diamond table may include a single nominal size of diamond grit or multi-modal mixtures of different grain sizes implemented in single layer and multi layer configurations.

It is also contemplated that other diamond table structures may be utilized. For example, as described in U.S. Provisional Patent Application Serial No. 61/232,265, filed on August 7, 2009, now U.S. Patent Application Serial No. 12/852,313, filed on August 6, 2010, which claims the benefit thereof, embodiments of the present disclosure may be implemented using polycrystalline diamond compacts including hard polycrystalline materials comprising *in situ* nucleated smaller grains of diamond interspersed and inter-bonded with larger diamond grains, wherein the average size of the larger diamond grains may be at least about 250 times greater than the average size of the smaller, in situ nucleated smaller diamond grains.

The catalyst 204, which comprises a metal or alloy of a Group VIII metal conventionally employed in diamond compact fabrication (*e.g.*, iron, cobalt, nickel), or other Group VIII metal or alloy thereof, and the catalyst may be supplied in the supporting substrate 206, if a substrate is employed, or may be admixed with the diamond grit. Both techniques are conventional.

In forming the diamond table 202, high pressure, high temperature (HPHT) processing is used to stimulate diamond-to-diamond bonding in the presence of catalyst 204 to form a polycrystalline structure. While conventional HPHT processing using Group VIII catalysts is generally carried out in a nominal range of 5 to 5.5 GPa and possibly slightly higher, diamond tables 202 of embodiments of the present invention are formed using a pressure of at least about 6.5 GPa. One suitable pressure is about 6.8 GPa. Even higher pressures, such as at least about 7 GPa, at least about 7.5 GPa, at least about 7.7 GPa, and at least about 8 GPa may also be employed. Further, it is contemplated that pressures of about 9 GPa or greater (*e.g.*, 10 GPa, 11 GPa, and higher) may be employed. In some embodiments, the diamond tables 202 of embodiments of the present invention may be formed at temperatures ranging, for example, from 1,100° C to 1,800° C.

When using HPHT processing of at least about 6.5 GPa, more compaction of the diamond grit is effected, as well as plastic deformation of the diamond grit particles, and stronger diamond-to-diamond bonding is achieved. Enhanced "green" packing density (*i.e.*, before HPHT processing), achieved by use of a multi-modal grit mixture, aids compaction of the diamond grit during HPHT processing and formation of a stronger, higher-strength, more durable diamond table.

A result of the tighter compaction, which leads to fewer and smaller voids, or interstices, between diamond grains, is a reduction of catalyst content in the sintered diamond table 202. While an advantage, the foregoing structure is also more difficult to process in order to remove the catalyst.

In act 110 (FIG. 1), the catalyst 204 is at least substantially removed from at least one portion of the diamond table 202 by, for example, leaching the catalyst 204 to a depth from the cutting face 210, the chamfer 214 and at least a portion of the side wall 212 of diamond table 202. Each of such surfaces may be referred to, for the sake of convenience and not limitation, as a "working surface." Catalyst may be removed from portions of the diamond table adjacent a working surface to a desired depth, for example, from about 40 microns to about 400 microns. For example, a depth of between about 100 microns and about 250 microns is believed to be particularly effective. In some embodiments, portions of the diamond table 202 may be "deep" leached, for example, to a depth of 250 microns or greater. In other embodiments, portions of the diamond table 202 may be leached, for example, to a depth of less than 100 microns. Such catalyst removal from one or more portions of the diamond table 202, rendering one or more portions F, shown in broken lines, of resulting diamond table 202′ at least substantially free of catalyst, enhances thermal stability of the diamond table during use, as known to those of ordinary skill in the art. The presence of the catalyst 204 in another region or regions of the diamond table 202′ may enhance bulk cutting element durability and impact strength thereof.

The use of ultra high pressure processing in accordance with embodiments of the present disclosure enhances durability and chipping resistance of the cutting edge 216, thus solving a notable problem experienced with state of the art PDC cutting elements.

In some embodiments, such as is illustrated in FIGS. 4A and 4B, a diamond table 402 of a polycrystalline diamond compact 400 (*e.g.*, free-standing polycrystalline diamond compact, gage trimmers, *etc.*) may be free-standing and substantially free of catalyst in its entirety, and any surface of the diamond table 402 as placed on an earth-boring tool may comprise a working surface, depending upon the orientation of the polycrystalline diamond compact 400 on the tool.

Any exposed surface of diamond table 202 not to be leached may be masked or otherwise protected by techniques known to those of ordinary skill in the art. If a substrate 206 is employed, the substrate 206 may be likewise protected from damage during the leaching process by conventional techniques. A variety of solvents may be employed for the leaching process. Specifically, as known in the art and described more fully in the aforementioned U.S. Patent No. 5,127,923 and in U.S. Patent No. 4,224,380, aqua regia (a mixture of concentrated nitric acid (HNO_3) and concentrated hydrochloric acid (HCl)) may be used to substantially remove the catalyst 204 from interstitial voids between the diamond crystals of the diamond table and from the crystal surfaces. It is also known to use boiling hydrochloric acid (HCl) and boiling hydrofluoric acid (HF), as well as mixtures of HF and HNO_3 in various ratios. Boiling HCl may be effective to remove catalyst from diamond tables 202 of polycrystalline diamond compacts 200 of embodiments of the present invention. Other catalyst removal processes are known, and may find utility in implementation of embodiments of the present invention. For example, pressures above atmospheric may be employed with a solvent, electrochemical leaching may be employed, microwave energy may be applied in the presence of a solvent, different solvents may be applied sequentially, or combinations of the foregoing approaches.

The resulting structure (FIG. 2B) is diamond table 202' that is at least substantially free of the catalyst 204 to a selected depth 220 from one or more of the cutting face 210, the chamfer 214 and at least a portion of the side wall 212 of diamond table 202, diamond table 202′ remaining bonded to supporting substrate 206.

Referring to FIG. 3 of the drawings, an earth boring-tool 500 in the form of a rotary drag bit is shown. As used herein, the term "earth-boring tool" includes and encompasses drag bits, roller cone bits, hybrid bits, reamers, mills and other subterranean tools for drilling and enlarging well bores.

The earth-boring tool 500 configured as a rotary drag bit includes bit body 505 having a shank 510 at one longitudinal end thereof and a face 515 at an opposing end thereof. The shank 510 includes threads configured to API standards and adapted for connection to a component of a drill string (not shown). The face 515 may include a plurality of generally radially extending blades 520 thereon forming fluid courses 525 therebetween extending to junk slots 530 between circumferentially adjacent blades 520. The bit body 505 may comprise a tungsten carbide matrix or a steel body, both as well known in the art.

Blades 520 may include a gage region 535 which is configured to define the outermost radius of the drill bit 500 and, thus, the radius of the wall surface of a bore hole drilled thereby. Gage regions 535 comprise longitudinally upward (as the drill bit 500 is oriented during use) extensions of blades 520 and may have wear-resistant inserts or coatings, such as cutting elements, or hardfacing material, on radially outer surfaces thereof as known in the art to inhibit excessive wear thereto.

The face 515, and in some embodiments the blades 520, include a plurality of cutting elements 540 having tables 545, at least some of which cutting elements 540 exhibit structure according to an embodiment of a polycrystalline diamond element 200, 400 of the present disclosure. The cutting elements 540 are positioned to cut a subterranean formation being drilled while the earth-boring tool 500 is rotated under weight on bit (WOB) in a bore hole about centerline 550.

As stated above, the gage regions 535 may include gage trimmers 555, at least some of which may exhibit structure according to an embodiment of a polycrystalline diamond element 200, 400 of the present disclosure, each gage trimmer 555 including a PDC table 545, such tables being configured with an edge (not shown) to trim and hold the gage diameter of the bore hole, and pads on the gage which contact the walls of the bore hole and stabilize the bit in the hole.

During drilling, drilling fluid is discharged through nozzle assemblies 560 located in nozzle ports 565 in fluid communication with the face 515 of bit body 505 for cooling the PDC tables 545 of cutting elements 540 and removing formation cuttings from the face 515 of the earth-boring tool 500 into fluid courses 525 and junk slots 530. The apertures 570 of nozzle assemblies 560 may be sized for different fluid flow rates depending upon the desired flushing required at each group of cutting elements 540 to which a particular nozzle assembly 460 directs drilling fluid.

The following example serves to explain embodiments of the present invention in more detail. This example is not to be construed as being exhaustive or exclusive, or otherwise limiting, as to the scope of embodiments of the present invention.

Example 1

FIGS. 5 and 6 depict the results of drilling operations performed on a subterranean formation with a drill bit carrying polycrystalline diamond elements employed as cutting elements in accordance with an embodiment of the present disclosure and with a drill bit carrying conventional cutting elements. FIG. 5 shows a graph illustrating the results of multiple drilling runs preformed with a drill bit carrying cutting elements with conventional cutting tables that were formed at a pressure of approximately 5.5 GPa. FIG. 5 further shows a similar drilling run completed on the same formation with a drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 6.8 GPa in accordance with embodiments of the present disclosure. The graph of FIG. 5 illustrates the distance drilled in each drilling run versus the rate of penetration (ROP) of the drill bit. The distance drilled is presented on the x-axis of the graph and ranges from 4,500 feet to 8,000 feet (approximately 1,372 meters to 2,438 meters). The ROP is presented on the y-axis of the graph and ranges from 0 feet per hour (feet/hour) to 100 feet per hour (feet/hour) (approximately 0 meters per second (meters/second) to 0.0085 meters per second (meters/second)).

FIG. 6 shows a graph illustrating the results of the multiple drilling runs preformed with the drill bit carrying cutting elements with conventional cutting tables that were formed at a pressure of approximately 5.5 GPa and the drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 6.8 GPa in accordance with embodiments of the present disclosure. The graph of FIG. 6 illustrates the depth in and depth out in each drilling run versus ROP of the drill bit. The ROP is presented on the x-axis of the graph and ranges from 45 feet per hour (feet/hour) to 70 feet per hour (feet/hour) (approximately

0.0038 meters per second (meters/second) to 0.0059 meters per second (meters/second)). The distance drilled is presented on the y-axis of the graph and ranges from 9,500 feet to 1,500 feet (approximately 2,896 meters to 457 meters).

As can been seen in FIGS. 5 and 6, the drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 6.8 GPa exhibited the ability to drill a longer distance (*i.e.*, a greater distance between depth in and depth out) than the drill bit carrying cutting elements with conventional cutting tables that were formed at a pressure of approximately 5.5 GPa. Furthermore, the drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 6.8 GPa was able to operate at ROP similar to or greater than the ROP of the drill bit carrying cutting elements with conventional cutting tables that were formed at a pressure of approximately 5.5 GPa. For example, the average distance for the drilling runs of the drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 6.8 GPa was 6,716 feet (approximately 2,047 meters) and the ROP was 59.42 feet per hour (feet/hour) (approximately 0.0050 meters per second (meters/second)). The average distance for the drilling runs of the drill bit carrying cutting elements with cutting tables that were formed at a pressure of approximately 5.5 GPa was 5,976 feet (approximately 1,821 meters) and the ROP was 48.95 feet per hour (feet/hour) (approximately 0.0041 meters per second (meters/second)).

In view of the above, embodiments of the present invention may provide higher-strength and more durable polycrystalline diamond elements as compared to conventional polycrystalline diamond elements. For example, polycrystalline diamond elements formed at ultra high pressure in accordance with embodiments of the present invention may aid compaction of the diamond grit during HPHT processing and formation of stronger, higher-strength, more durable elements such as, for example, diamond tables for PDC cutting elements as compared to conventional diamond tables. Further, such polycrystalline diamond elements may provide diamond tables for cutting elements that enable the removal of a catalyst from all or a part of the diamond tables without substantially weakening the working surfaces of the diamond tables which may cause undesirable, premature failure of the diamond tables. Also, polycrystalline diamond elements formed at ultra high pressure may enhance the durability and chipping resistance of the cutting edge of the diamond tables, thus solving a notable problem experienced with state of the art PDC cutting elements.

Although the foregoing description contains many specifics and examples, these are not limiting the scope of the present invention, but merely as providing illustrations of some embodiments. Similarly, other embodiments of the disclosure may be devised which do not depart from the scope thereof. The scope of this invention is, therefore, indicated and limited only by the appended claims and their legal equivalents, rather than by the foregoing description. All additions, deletions and modifications to the invention as disclosed herein and which fall within the meaning of the claims are embraced within their scope.

Additional non-limiting example Embodiments are described below.

Embodiment 1: A method of forming a polycrystalline diamond element, comprising: forming a polycrystalline diamond compact comprising a catalyst including a Group VIII metal or alloy at a pressure of at least about 6.5 GPa; and at least substantially removing the catalyst from at least a portion of the polycrystalline diamond compact.

Embodiment 2: The method of Embodiment 1, wherein forming the polycrystalline diamond compact comprises forming a diamond table on a supporting substrate.

Embodiment 3: The method of Embodiments 1 or 2, wherein forming the polycrystalline diamond compact comprises forming a free-standing polycrystalline diamond compact.

Embodiment 4: The method of any one of Embodiments 1 through 3, wherein at least substantially removing the catalyst from at least a portion of the polycrystalline diamond compact is effected by leaching.

Embodiment 5: The method of any one of Embodiments 1 through 4, further comprising leaching a portion of the polycrystalline diamond compact to a depth of at least about 100 microns.

Embodiment 6: The method of Embodiment 5, wherein leaching a portion of the polycrystalline diamond compact to a depth of at least 100 microns comprises leaching a portion of the polycrystalline diamond compact to a depth of at least about 250 microns.

Embodiment 7: The method of any one of Embodiments 1 through 6, wherein at least substantially removing the catalyst from a portion of the polycrystalline diamond compact is effected to a depth of between about 40 microns and about 400 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact.

Embodiment 8: The method of Embodiment 7, wherein at least substantially removing the catalyst from a portion of the polycrystalline diamond compact is effected to a depth of between about 100 microns and about 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact.

Embodiment 9: The method of any one of Embodiments 1 through 8, wherein at least substantially removing the catalyst from at least a portion of the polycrystalline diamond compact comprises substantially removing the catalyst from substantially an entirety of the polycrystalline diamond compact.

Embodiment 10: The method of any one of Embodiments 1 through 9, wherein forming the polycrystalline diamond compact comprises forming the polycrystalline diamond compact from natural diamond grit, synthetic diamond grit, or a combination thereof.

Embodiment 11: The method of any one of Embodiments 1 through 10, wherein forming the polycrystalline diamond compact comprises employing a multi-modal diamond grit mixture.

Embodiment 12: The method of any one of Embodiments 1 through 11, wherein forming the polycrystalline diamond compact consists of forming the polycrystalline diamond compact from the group selected from a single layer of diamond grit of a single nominal size, a single layer of diamond grit employing a multi-modal diamond grit mixture, two or more layers of diamond grit with diamond grit within each layer being of a substantially common nominal size, and two or more layers of diamond grit, at least one of the layers comprising a multi-modal diamond grit mixture.

Embodiment 13: The method of any one of Embodiments 1 through 12, wherein forming a polycrystalline diamond compact at pressure of at least about 6.5 GPa comprises forming the polycrystalline diamond compact at a pressure of at least about 6.8 GPa, at least about 7 GPa, at least about 7.7 GPa, at least about 8 GPa, or at least about 9 GPa.

Embodiment 14: A polycrystalline diamond element, comprising: a polycrystalline diamond compact table comprising a catalyst including a Group VIII metal or alloy and formed at a pressure of at least about 6.5 GPa; wherein at least a portion of the polycrystalline diamond compact table is substantially free of the catalyst.

Embodiment 15: The polycrystalline diamond element of Embodiment 14, further comprising a supporting substrate secured to a surface of the polycrystalline diamond compact table.

Embodiment 16: The polycrystalline diamond element of Embodiments 14 or 15, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises a depth of between about 80 microns and about 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact table.

Embodiment 17: The polycrystalline diamond element of any one of Embodiments 14 through 16, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises a depth of at least 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact table.

Embodiment 18: The polycrystalline diamond compact element of any one of Embodiments 14 through 17, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises substantially an entirety of the polycrystalline diamond table.

Embodiment 19: The polycrystalline diamond element of any one of Embodiments 14 through 18, wherein the polycrystalline diamond compact table comprises natural diamond grit, synthetic diamond grit, or a combination thereof.

Embodiment 20: The polycrystalline diamond element of any one of Embodiments 14 through 19, wherein the polycrystalline diamond compact table exhibits a multi-modal diamond grain distribution.

Embodiment 21: The polycrystalline diamond element of any one of Embodiments 14 through 20, wherein the polycrystalline diamond compact table consists of the group selected from a single layer of diamond grains of a single nominal size, a single layer of diamond grains having a multi-modal diamond grain distribution, two or more layers of diamond grains with grains of each layer being of a substantially common nominal size, and two or more layers of diamond grains, at least one of the layers comprising a multi-modal diamond grain distribution.

Embodiment 22: The polycrystalline diamond element of any one of Embodiments 14 through 21, wherein the polycrystalline diamond compact table is formed at a pressure of at least about 6.8 GPa, at least about 7 GPa, at least about 7.7 GPa, at least about 8 GPa, or at least about 9 GPa.

Embodiment 23: An earth-boring tool, comprising: a body; and at least one cutting element carried by the body and comprising: a polycrystalline diamond compact table formed at a pressure of at least about 6.5 GPa, comprising a Group VIII metal or alloy catalyst and including at least a portion that is substantially free of the catalyst.

Embodiment 24: The earth-boring tool of Embodiment 23, further comprising a supporting substrate secured to a surface of the polycrystalline diamond compact table.

Embodiment 25: The method of Embodiment 1, further comprising leaching a portion of the polycrystalline diamond compact to a depth of less than about 100 microns.

AMENDED CLAIMS
received by the International Bureau on 23 June 2011 (23.06.2011)

What is claimed is:

1. A method of forming a polycrystalline diamond element, comprising:
forming a polycrystalline diamond compact comprising a catalyst including a Group VIII metal or alloy at a pressure greater than about 7 GPa; and
at least substantially removing the catalyst from at least a portion of the polycrystalline diamond compact.

2. The method of claim 1, wherein forming the polycrystalline diamond compact comprises forming a diamond table on a supporting substrate.

3. The method of claim 1, wherein forming the polycrystalline diamond compact comprises forming a free-standing polycrystalline diamond compact.

4. The method of claim 1, further comprising leaching a portion of the polycrystalline diamond compact to a depth of at least about 100 microns.

5. The method of claim 4, wherein leaching a portion of the polycrystalline diamond compact to a depth of at least 100 microns comprises leaching a portion of the polycrystalline diamond compact to a depth of at least about 250 microns.

6. The method of claim 1, wherein at least substantially removing the catalyst from a portion of the polycrystalline diamond compact is effected to a depth of between about 100 microns and about 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact.

7. The method of claim 1, wherein at least substantially removing the catalyst from at least a portion of the polycrystalline diamond compact comprises substantially removing the catalyst from substantially an entirety of the polycrystalline diamond compact.

8. The method of claim 1, wherein forming the polycrystalline diamond compact comprises forming the polycrystalline diamond compact from natural diamond grit, synthetic diamond grit, or a combination thereof.

9. The method of claim 1, wherein forming the polycrystalline diamond compact consists of forming the polycrystalline diamond compact from the group selected from a single layer of diamond grit of a single nominal size, a single layer of diamond grit employing a multi-modal diamond grit mixture, two or more layers of diamond grit with diamond grit within each layer being of a substantially common nominal size, and two or more layers of diamond grit, at least one of the layers comprising a multi-modal diamond grit mixture.

10. The method of any one of claims 1 through 8, wherein forming a polycrystalline diamond compact at pressure of greater than about 7 GPa comprises forming the polycrystalline diamond compact at a pressure of at least about 7.7 GPa, at least about 8 GPa, or at least about 9 GPa.

11. A polycrystalline diamond element, comprising:

a polycrystalline diamond compact table comprising a catalyst including a Group VIII metal or alloy and formed at a pressure of greater than about 7 GPa;

wherein at least a portion of the polycrystalline diamond compact table is substantially free of the catalyst.

12. The polycrystalline diamond element of claim 11, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises a depth of between about 80 microns and about 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact table.

13. The polycrystalline diamond element of claim 11, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises a depth of at least 250 microns from at least one of a cutting face, a side wall, and a chamfer of the polycrystalline diamond compact table.

14. The polycrystalline diamond compact element of claim 13, wherein the at least a portion of the polycrystalline diamond compact table substantially free of the catalyst comprises substantially an entirety of the polycrystalline diamond table.

15. The polycrystalline diamond element of claim 11, wherein the polycrystalline diamond compact table exhibits a multi-modal diamond grain distribution.

16. The polycrystalline diamond element of claim 11, wherein the polycrystalline diamond compact table consists of the group selected from a single layer of diamond grains of a single nominal size, a single layer of diamond grains having a multi-modal diamond grain distribution, two or more layers of diamond grains with grains of each layer being of a substantially common nominal size, and two or more layers of diamond grains, at least one of the layers comprising a multi-modal diamond grain distribution.

17. The polycrystalline diamond element of claim 11, wherein the polycrystalline diamond compact table is formed at a pressure of at least about 7.7 GPa, at least about 8 GPa, or at least about 9 GPa.

18. An earth-boring tool, comprising:

a body; and

at least one polycrystalline diamond element as recited in any one of claims 11 through 17 carried by the body.

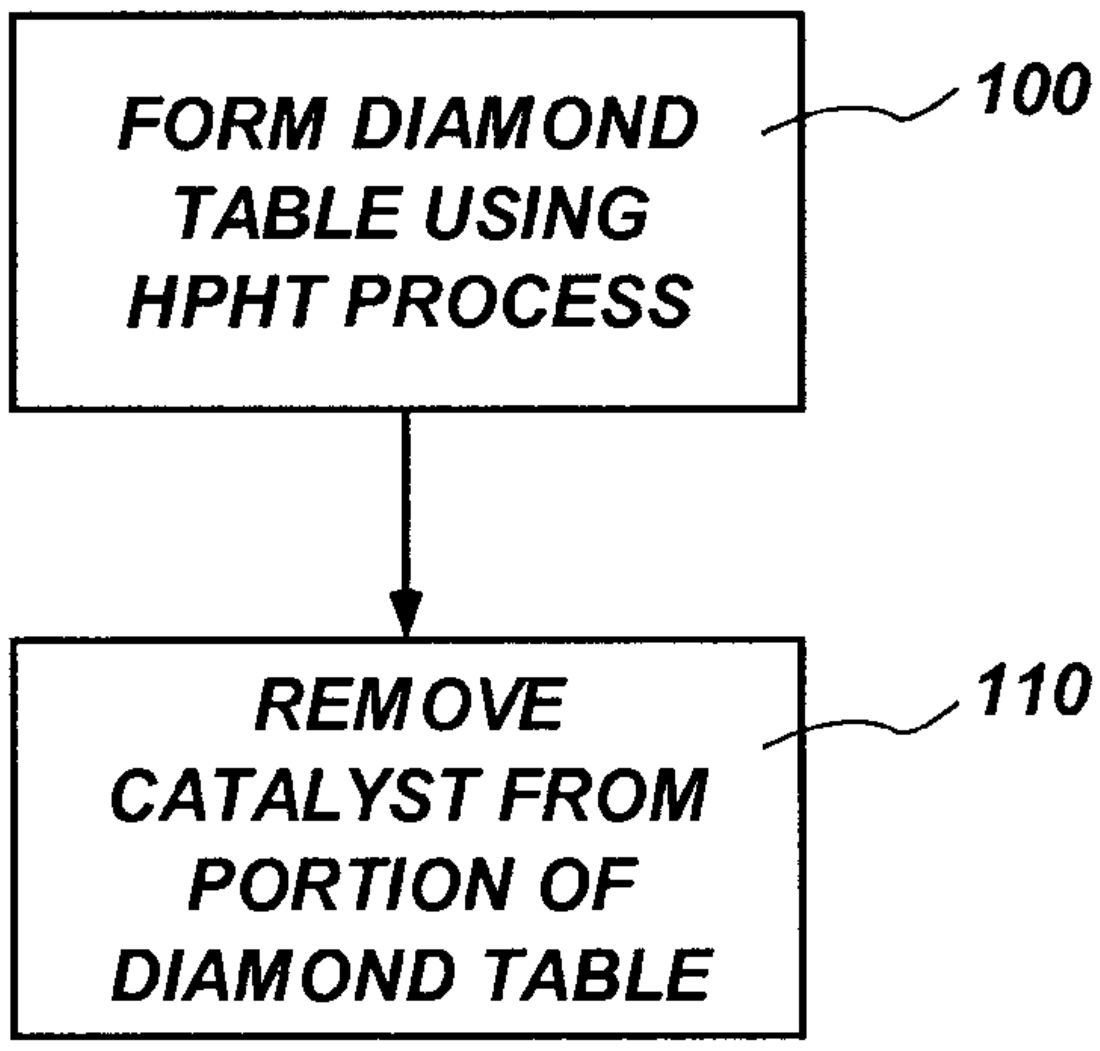


FIG. 1

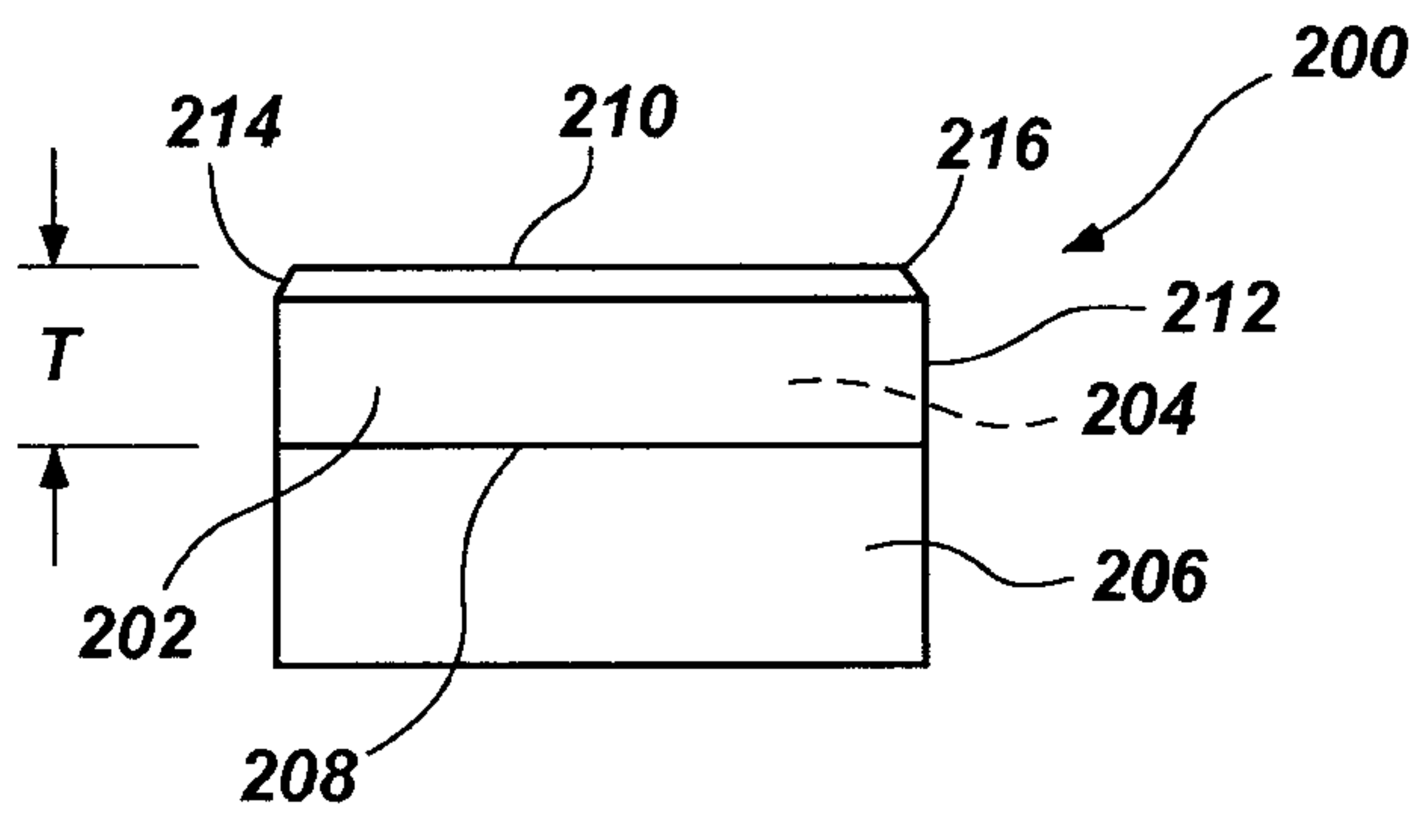


FIG. 2A

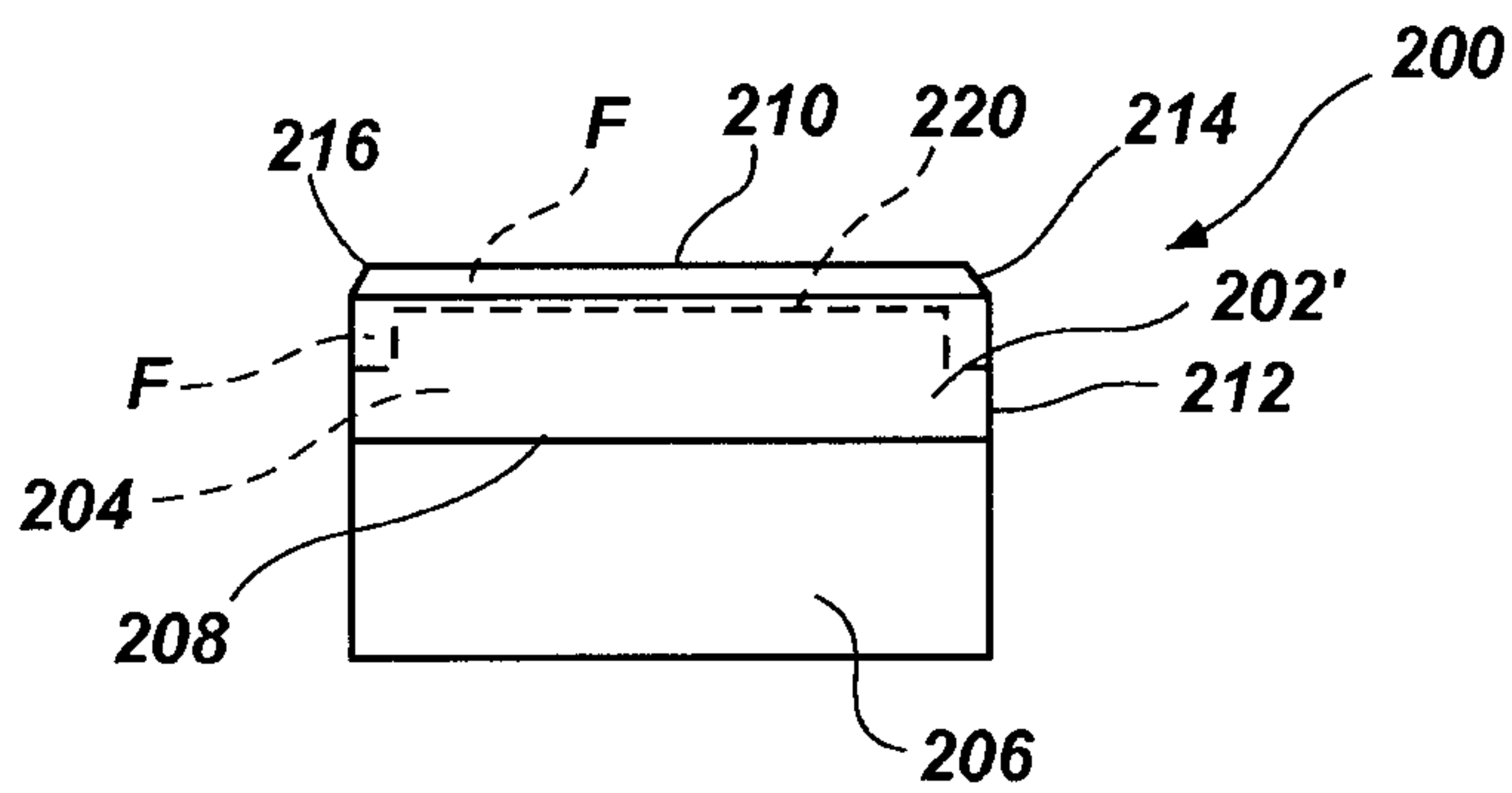


FIG. 2B

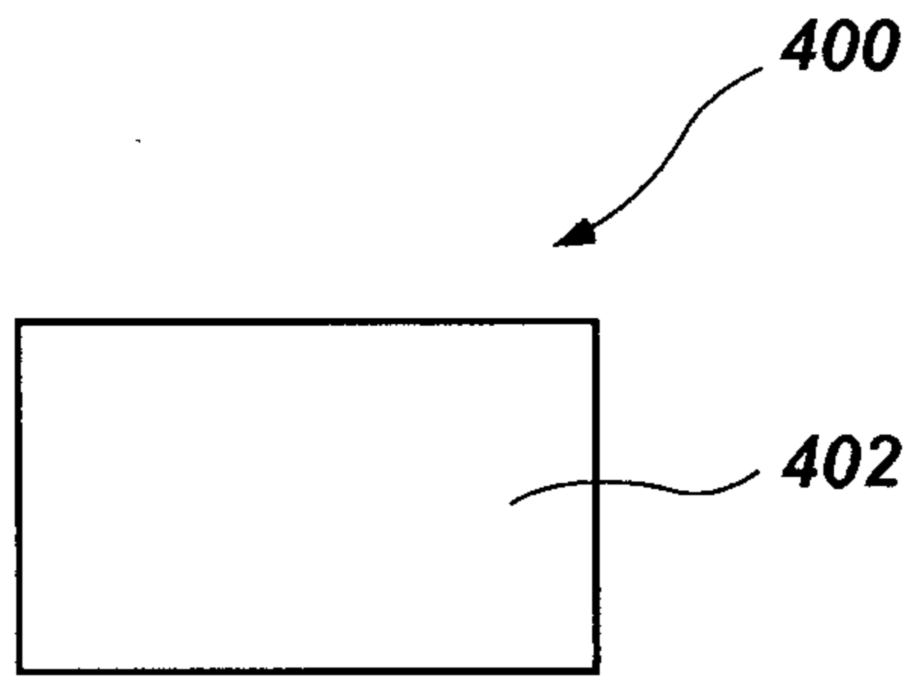


FIG. 4A

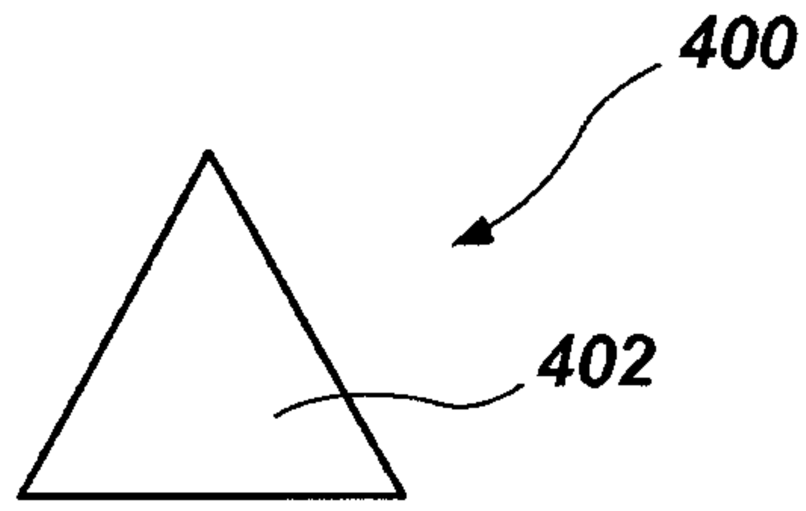
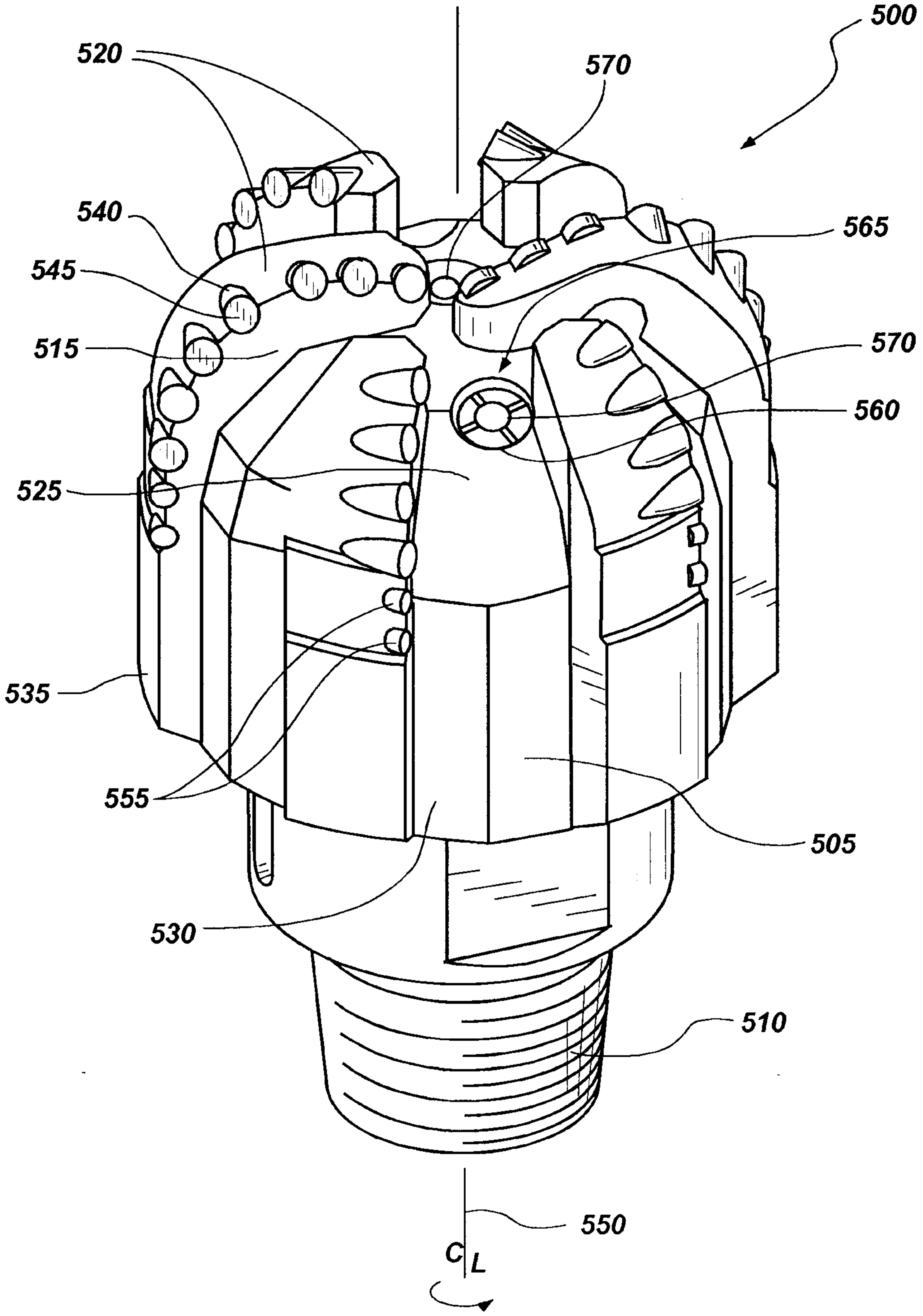


FIG. 4B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565
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550
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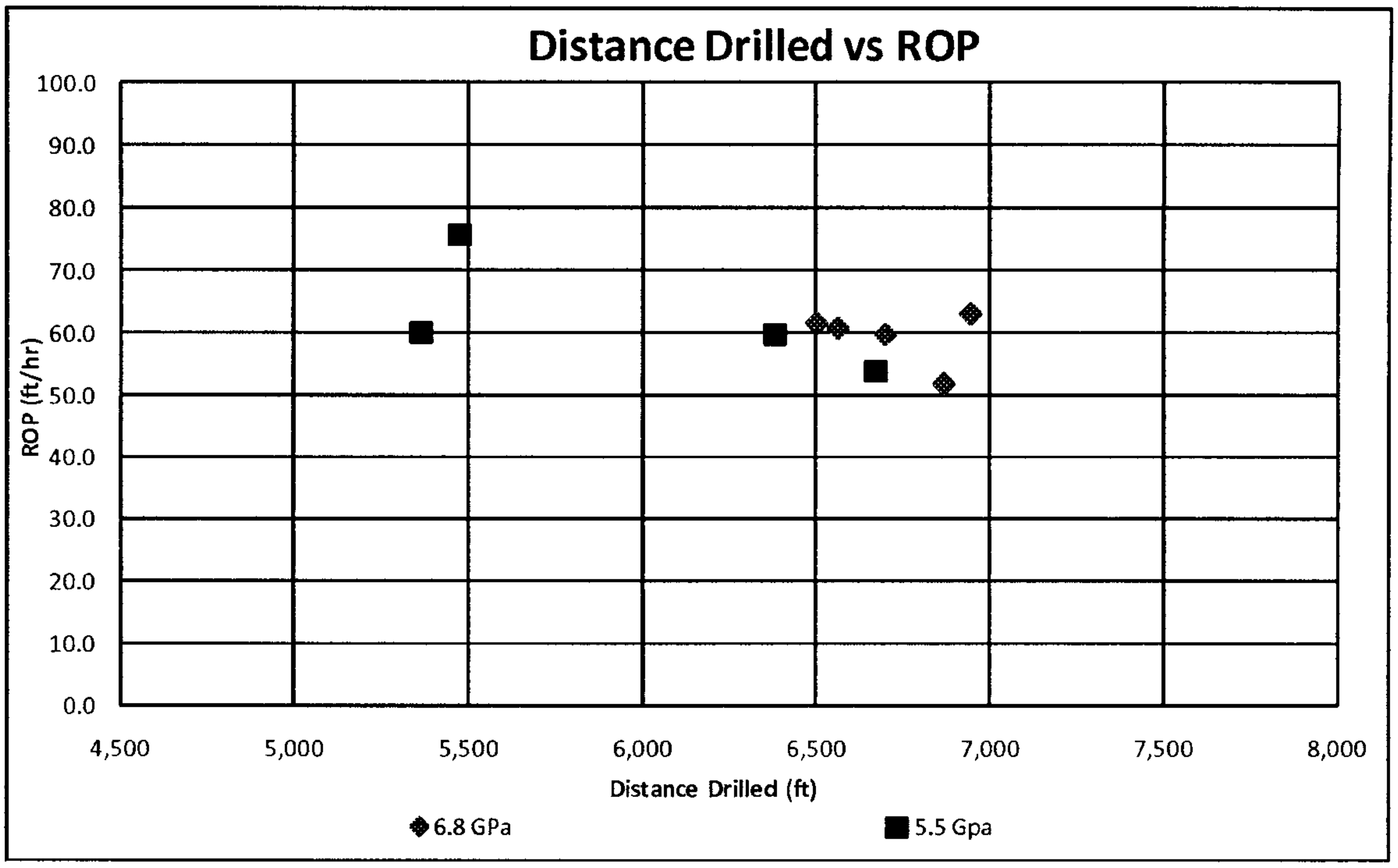
FIG. 3


Distance Drilled vs ROP
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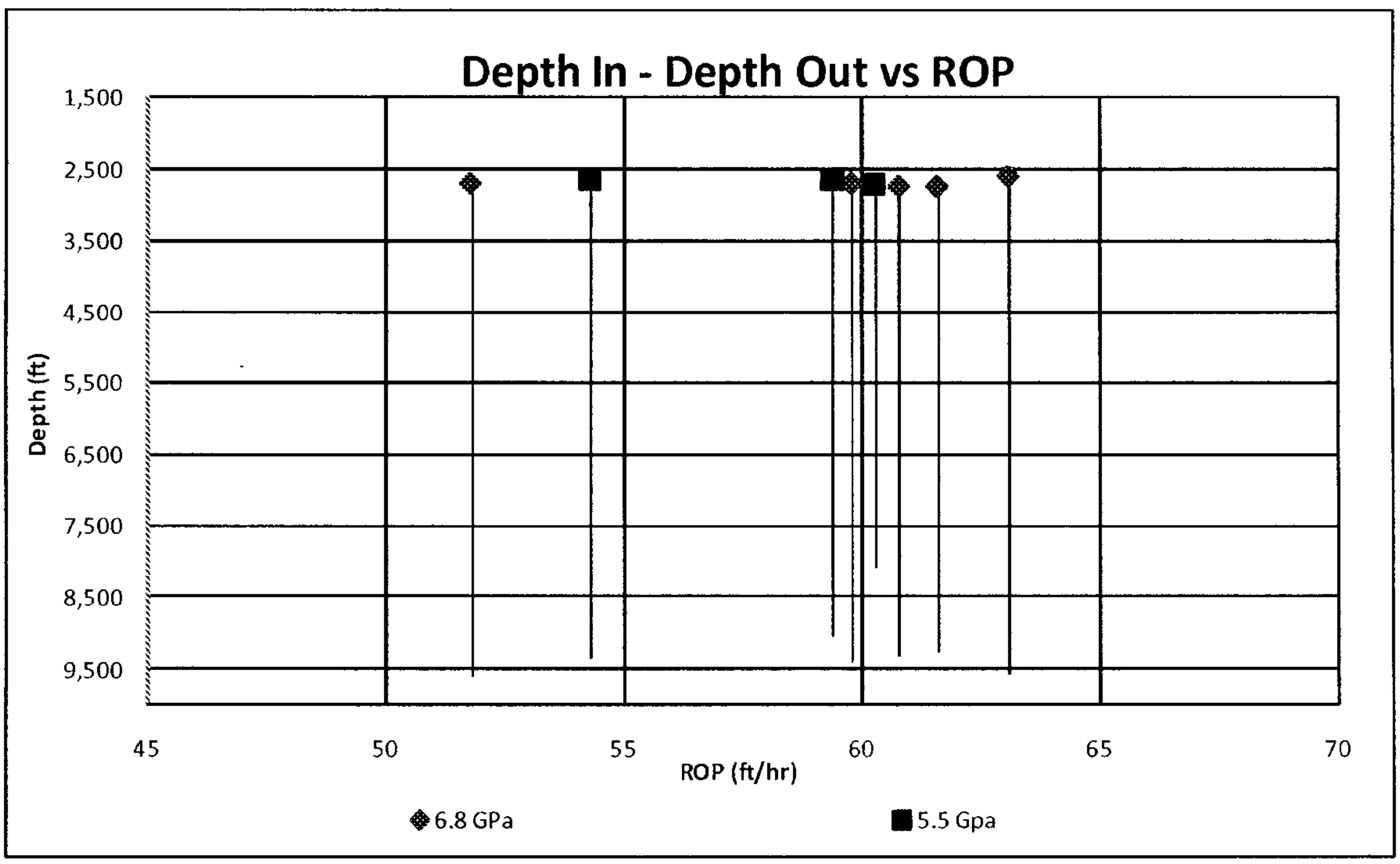
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
ROP (ft/hr)
4,500
5,000
5,500
6,000
6,500
7,000
7,500
8,000
Distance Drilled (ft)
6.8 GPa
5.5 Gpa

FIG. 5


Depth In - Depth Out vs ROP
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3,500
4,500
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6,500
7,500
8,500
9,500
Depth (ft)
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50
55
60
65
70
ROP (ft/hr)
6.8 GPa
5.5 Gpa

FIG. 6

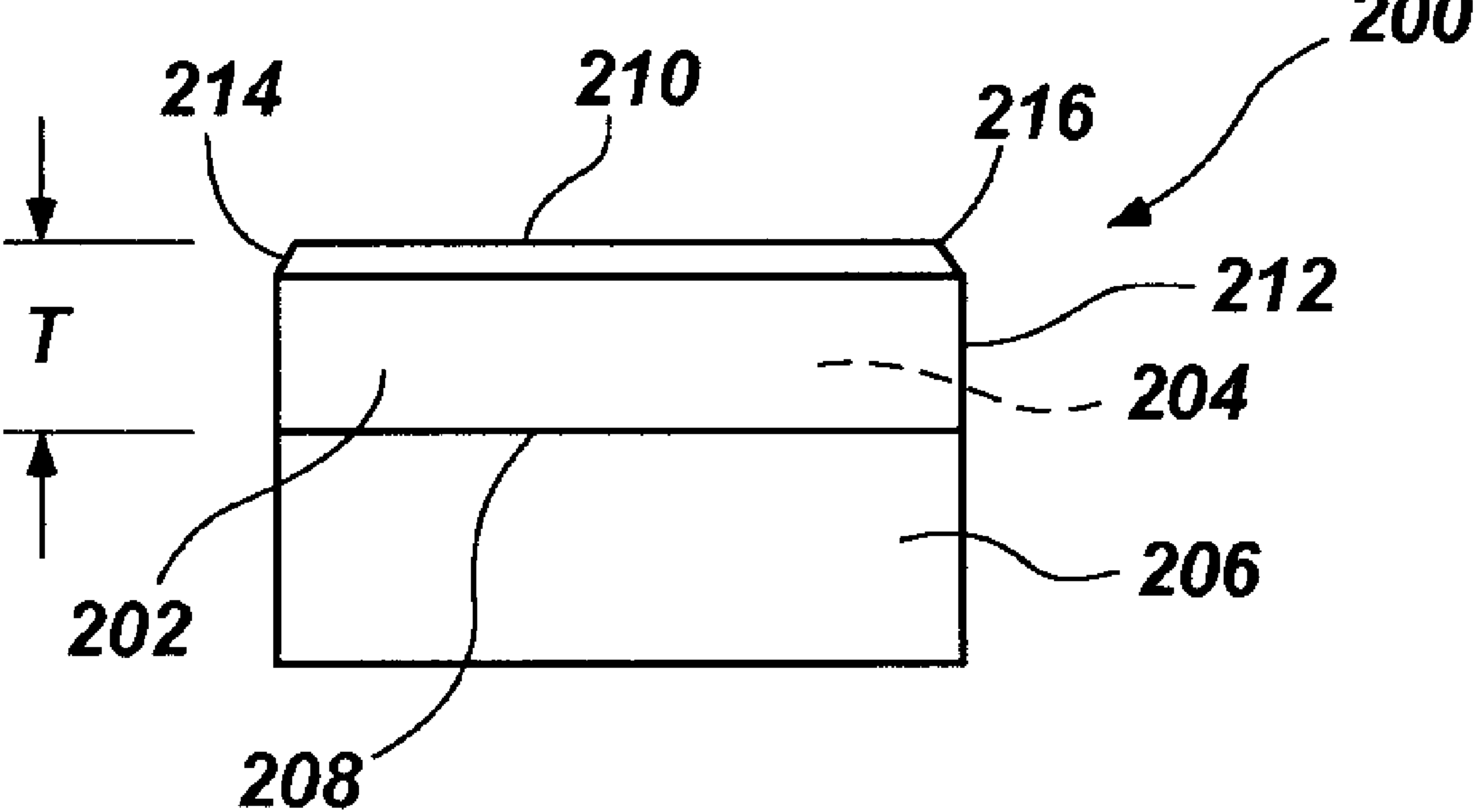

FIG. 2A