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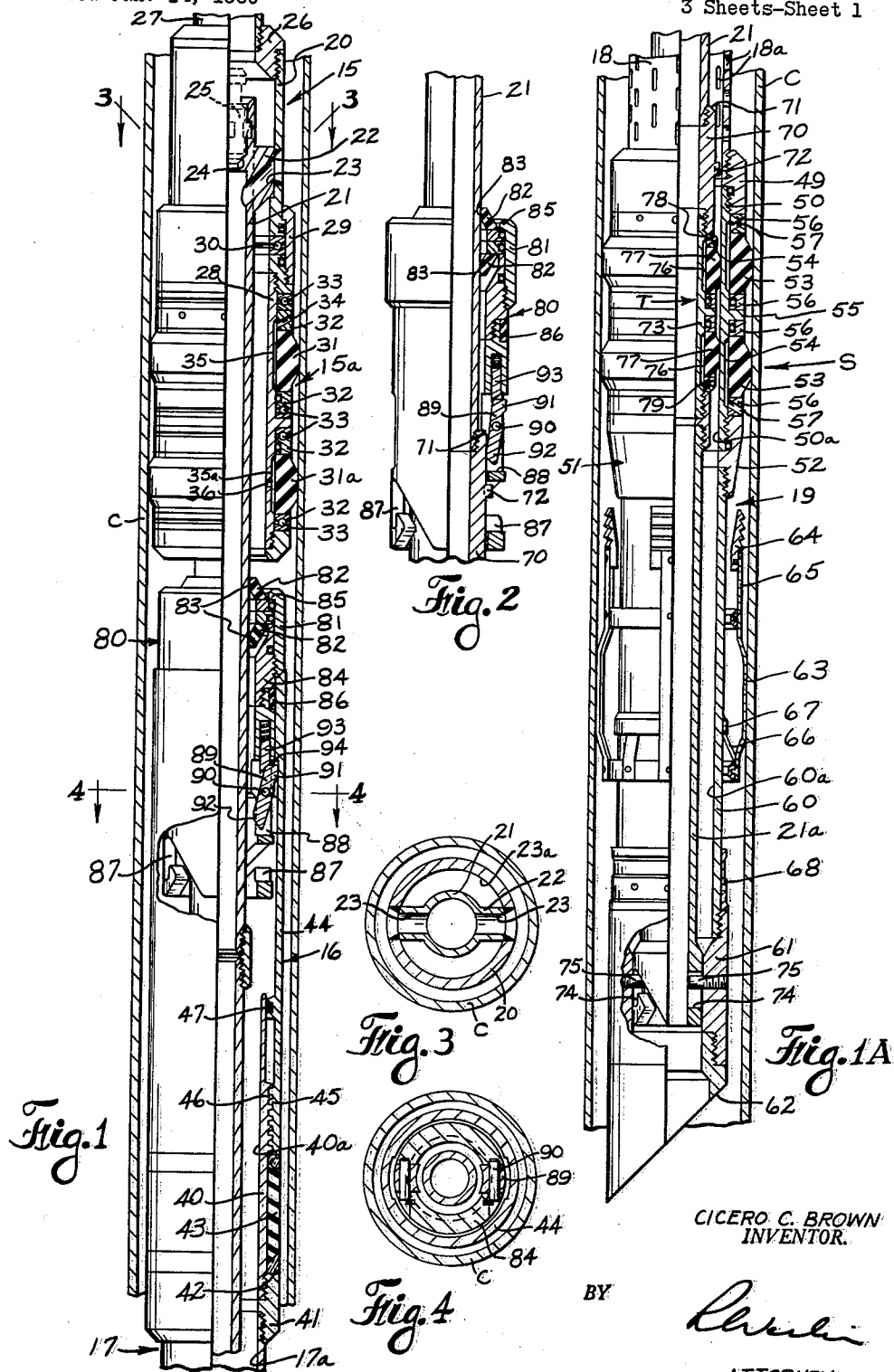
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3,062,284

GRAVEL PACKING OF WELLS AND APPARATUS THEREFOR

Filed Jan. 14, 1960

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

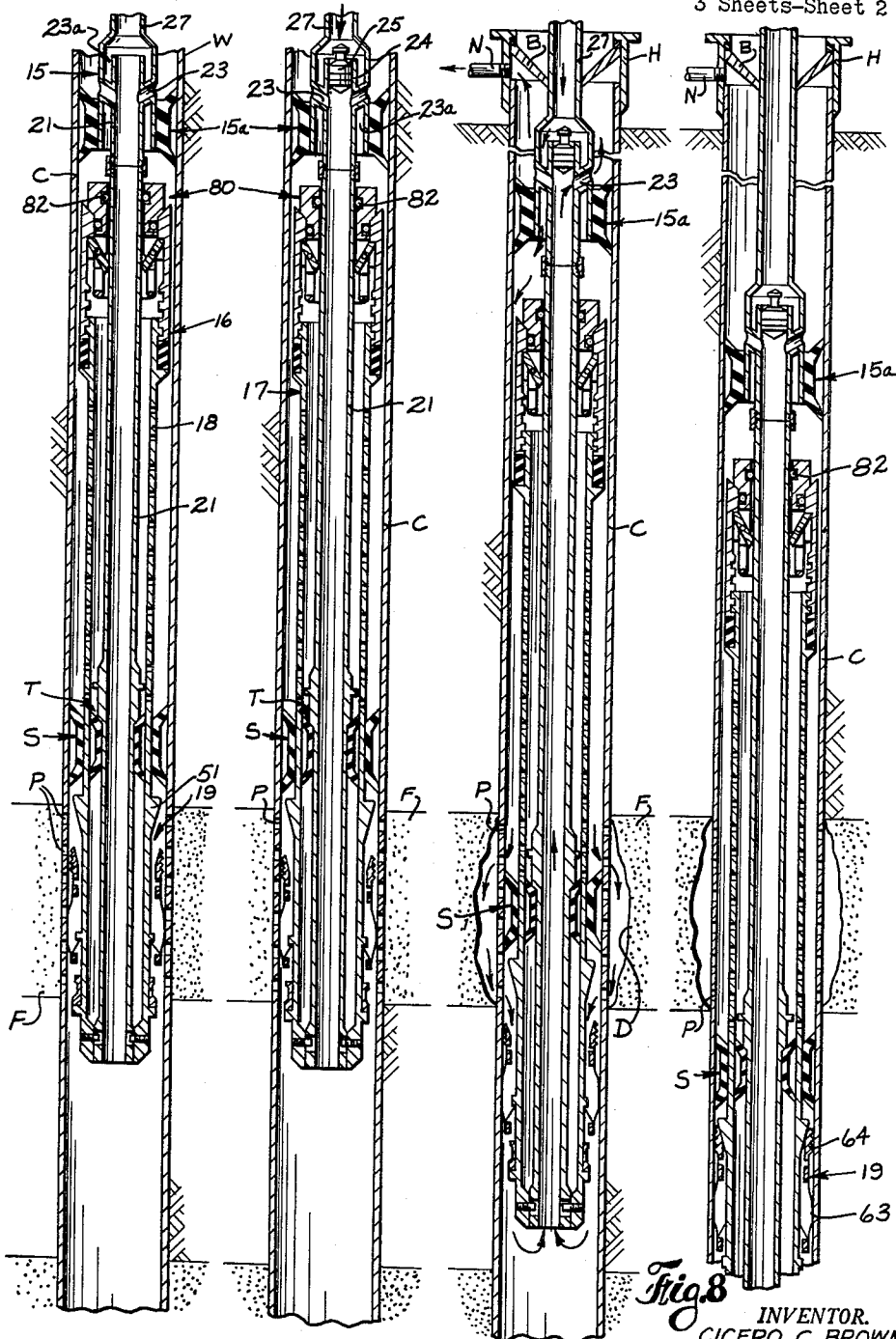


Fig. 5

Fig. 6

Fig. 7 BY

Fig. 8
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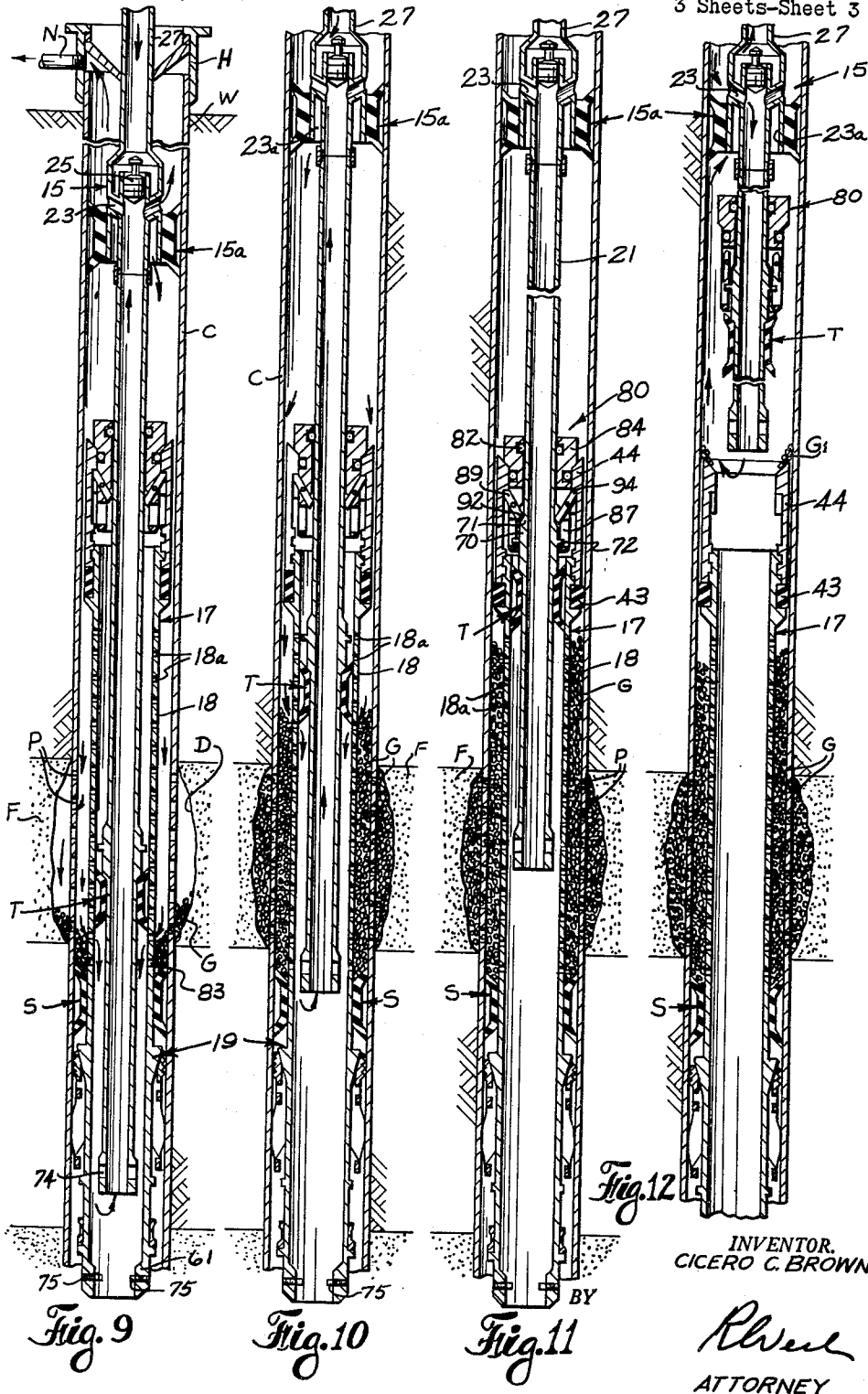
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GRAVEL PACKING OF WELLS AND APPARATUS THEREFOR

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12 Claims. (Cl. 166—19)

This invention relates to the gravel packing of wells and particularly to an improved method for gravel packing and apparatus therefor.

Gravel packing is frequently employed to form a filter body between a relatively unconsolidated oil producing formation in a well bore and the production pipe. Normally, the latter includes a section of pipe, commonly termed a "liner," having a plurality of narrow spaced-apart slots or screen-covered openings through which formation fluids enter the production pipe from the formation while the gravel body interposed between the liner and the formation serves to screen out fine sand and the like from the well fluids so that cleaned fluids may enter the production pipe. Where the screen liner is set in open hole, the gravel pack also serves to support the unconsolidated formation. Where the screen liner is set inside a casing having perforations communicating with the formation, the gravel pack functions primarily as a filter element.

Heretofore, gravel packing tools have comprised separate liner setting tools and gravel-placing devices which have been relatively complicated in form and subject to various type of difficulties in setting them in place and in conducting the gravel packing operation. In particular, in more conventional systems, difficulty is experienced in determining with certainty that the gravel pack is deposited at the proper location relative to the producing formation. Also, because of the narrow spaces and passages in the apparatus through which the gravel packing must be conducted, bridging by the gravel often will occur at points above the desired location, so that production is interfered with and ineffective support of the formation will occur. Moreover, with present gravel-packing systems, no good indication can be obtained to apprise the operator that such bridging has occurred or as to its locations relative to the producing formation.

When gravel packing is between a screen liner and a casing having perforations opposite the producing formation, precise location of the gravel pack is especially important because the length of the perforated section of the casing will often be quite short, for example two or three feet or less in some cases and at the great depths of the producing formations such short sections can very easily be missed and the necessarily precise location of the gravel pack is very difficult to effect by conventional systems.

It is a primary object of the present invention, therefore, to provide a simplified tool structure or assembly which obviates the difficulties and complexities of more conventional gravel-packing structures and which, in particular, assures deposit of the gravel pack at the desired location under precise control.

An important object is to provide a tool assembly which includes a cross-over arrangement by which fluid may be selectively circulated through the tubing or inner pipe string to the annulus below an intervening seal packer or in the reverse direction from the annulus to the tubing string and thence back into the annulus above the intervening seal packer, the assembly including means for varying the elevation of the point of flow from the annulus to the tubing string to provide a tell-tale or indicator for the precise location of the casing perforations and the gravel pack.

A further object is the provision of a tool assembly in-

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cluding a screw-set liner hanger in combination with a seal packing for the well bore and cross-over means to deliver washing fluid to the production formation as well as gravel-carrying fluid for packing the annular space between the formation and the screen liner.

An additional object is the provision of an improved method for gravel packing a well bore.

Other and more specific objects and advantages of this invention will become more readily apparent from the following detailed description when read in conjunction with the accompanying drawing which illustrates a useful embodiment in accordance with this invention.

In the drawing:

FIGS. 1 and 1A, together, comprise a longitudinal quarter-sectional view of a tool assembly in accordance with this invention, the assembly being shown inside a well casing;

FIG. 2 is a detail of a portion of the tool assembly, showing some of the parts in a position differing from that shown in FIG. 1;

FIGS. 3 and 4 are cross-sectional views taken respectively along lines 3—3 and 4—4 of FIG. 1;

FIGS. 5, 6, 7 and 8 are diagrammatic views illustrating various positions of the tool assembly and parts thereof during several stages in the operation thereof preparatory to depositing gravel; and

FIGS. 9, 10, 11 and 12 are views similar to FIGS. 5 to 8, showing positions of the tool assembly and parts thereof during various stages of the gravel packing operation.

The tool assembly includes a series of sub-assemblies interconnected into one elongate structure insertable in a well casing C which lines the bore of a well W. Considered from the upper end thereof, the tool assembly includes a cross-over section, designated generally by the numeral 15, a screw-set packer, designated generally by the numeral 16, a screen liner 17, including a screen section 18 provided with screen slots 18a, and a liner hanger, designated generally by the numeral 19. Packer 16, liner 17 and liner hanger 19, together, constitute the "liner string" as that term is used hereinafter.

The cross-over section comprises an outer tubular shell 20, which carries a cross-over seal, designated generally by the numeral 15a, and an inner elongate tubular mandrel 21 concentric with and smaller in diameter than shell 20, and of a length sufficient to extend throughout the full length of the tool assembly. A cross-over head 22 connects mandrel 21 to shell 20 and is provided with lateral cross-over passages 23 which provide communication through the walls of mandrel 21 and shell 20 for fluid flow between the bore of mandrel 21 and the interior of casing C. Generally semi-circular longitudinal passages 23a (FIG. 3) are provided through head 22 around passages 23 so that fluid may flow either through the annulus between mandrel 21 and shell 20 or through passages 23 between the exterior of shell 20 and the interior of mandrel 21. A plug-receiving seat 24 is provided in the upper end of mandrel 21 above passages 23, and is adapted to receive a closure plug 25 (shown in broken lines in FIG. 1) for closing-off flow of fluid into the upper end of mandrel 21 at certain stages of the operation of the structure, as will be subsequently described. The upper end of shell 20 is adapted to be connected, by means of a collar 26, to an operating pipe string 27 which leads to the surface and through the bore of which operating fluid and gravel may be introduced into the tool assembly, as will subsequently appear. The lower end of shell 20 is rotatably connected to a tubular seal body 28 through a bearing housing 29, in which is mounted an anti-friction bearing 30 interposed between the lower end of shell 20 and the upper end of body 28, which forms an

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extension of housing 29. A pair of flexible resilient seal rings 31—31a, comprising the cross-over seal 15a, are mounted about the exterior of body 28 and rotatably seated thereon in longitudinally spaced annular grooves 35 and 35a, respectively. The ends of the seal rings are secured to end-rings 32—32 and each seal ring is mounted between roller bearings 33—33 mounted in the grooves 35, 35a, whereby body 28 may rotate freely with respect to seal rings 31—31a when the latter engage the wall of casing C. Fluid pressure from the interior of casing C may be imposed against the inner face of seal ring 31 through a passage 34 extending through the upper end ring 32 and communicating at one end with the exterior of body 28 at a point above seal ring 31 and at the other end with the interior of groove 35 behind seal ring 31. A fluid passage 36, through the wall of body 28, provides fluid communication between the bore of body 28 and the interior of groove 35a behind lower seal ring 31a and is adapted to transmit fluid pressure in casing C below seal ring 31a into groove 35a.

With the arrangement of the seal rings 31 and 31a on body 28, as described, it will be seen that fluid pressure on the exterior of the body may enter passage 34 and groove 35 to expand upper seal ring 31, while external fluid pressure may also enter through the lower end of the bore of body 28 and passage 36 into groove 35a behind lower seal ring 31a in order to expand the same.

The screw-set packer 16 comprises a tubular body 40, having an axial bore 40a, which is threadedly receiving at its lower end in a collar 41, the latter thereby providing an upwardly facing shoulder 42 about the exterior of body 40. Mounted about body 40 on shoulder 42 is a resilient sleeve packer 43, the upper end of which is engaged by the lower end of a tubular setting sleeve 44 which telescopes over the upper end of body 40 and is threadedly connected thereto by means of the internal threads 45 which engage external threads 46 on body 40. The lower end of setting sleeve 44 bears against the upper end of packer 43 and it will be evident that by rotation of sleeve 44 relative to body 40, packer 43 may be compressed against shoulder 42 and caused to expand radially into sealing engagement with casing C.

A secondary seal 47 is provided between setting sleeve 44 and the upper end of body 40 at a point above the threads 45, 46 to protect the threads against clogging by gravel or detritus carried by fluid passing through the bore of the tool assembly.

The lower end of collar 41 is threadedly connected to the upper end of liner 17, which has a bore 17a which is substantially flush with bore 40a of packer body 40. The lower end of liner 17 is connected, by means of a screw coupling 49, to a lower seal structure, designated generally by the letter S. Seal structure S includes a tubular body 50 having an axial bore 50a which is substantially flush with bores 17a and 40a. The upper end of lower seal body 50 is threadedly received in the lower end of coupling 49, while the lower end of seal body 50 is threadedly received in an expander collar 51, the exterior of which is shaped to provide a downwardly and inwardly tapering conical expander surface 52 which forms a part of liner hanger 19.

Seal structure S also includes a pair of flexible resilient seal rings 53—53 which are mounted about the exterior of body 50 and are seated therein in a pair of longitudinally spaced annular grooves 54—54, the upper one of which is defined between coupling 49 and an external shoulder 55 on body 50 located intermediate coupling 49 and collar 51, and lower one of which is defined between shoulder 55 and the upper end of expander coupling 51. The ends of each of the seal rings 53 are secured to end rings 56—56 which seat against the shoulders defining the related seating grooves 54. A passage 57 extends through the upper one of the end rings secured to the upper seal ring 53 and a similar passage 57 extends through the lower end ring 56 secured to the lower seal ring 53, the

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passages 57 providing communication between the interiors of the respective grooves 54 and the exterior of body 50 at points above and below the seal rings, whereby fluid pressure exteriorly of body 50 may be imposed against the inner faces of the seal rings to expand the latter into sealing engagement with the wall of casing C during operation of the device, as will be subsequently described.

Liner hanger 19 includes an anchor structure of a generally conventional type which is actuated by longitudinal movements of the tool string in order to anchor the liner to the well wall, such as casing C. This type of anchor mechanism and its operation are well-known and are described in detail in U.S. Patent No. 764,769, July 12, 1904, Robinson et al., and is further described in detail in conjunction with Liner Packers in my U.S. Patent No. 2,884,069, January 10, 1955. As will be seen (FIG. 1A), the hanger structure includes the tubular hanger body 60 which is threadedly secured at its upper end in the lower end of expander coupling 51 to form an extension of seal body 50 and has a bore 60a which is substantially flush with bore 50a. The lower end of body 60 is threadedly received in a tubular sub 61 which has a pointed guide shoe 62 connected to its lower end. Slidably mounted on hanger body 60 is a slip cage 63 having portions frictionally engageable with the wall of casing C. The upper end of cage 63 carries a plurality of toothed slips 64 mounted on upwardly extending spring arms 65, the slips being adapted to engage surface 52 of expander collar 51 whereby to urge slips 64 outwardly into gripping engagement with casing C in response to relative longitudinal movement between the liner string and the slip cage. A plurality of spring fingers 66 carried by cage 63 are engageable beneath an annular shoulder 67 on body 60 to hold the slips out of engagement with expander collar 51 and are releasable from shoulder 67 by means of a releasing sleeve 68 slidably mounted on body 60 below shoulder 67 and operable by longitudinal movements of the tool string. The release of the slip cage will permit relative movement between the liner string and the slips whereby the latter may engage expander collar 51 for expansion thereby and thus anchor the liner structure and seal body 50 to the wall of casing C, as illustrated in FIGS. 8 to 12. It will be understood that other types of anchor devices may be employed and the specific details thereof do not form a part of the present invention.

The lower end of mandrel 21 is threadedly received in a tubular collar 70, the upper end of which defines a downwardly sloping annular shoulder 71 about the exterior of mandrel 21. Collar 70 carries a pair of oppositely disposed, radially projecting J-lugs 72, the purpose of which will be subsequently described. A tubular seal body 73, of the same general form and construction as seal body 50, is screwed into the lower end of collar 70 and the lower end of seal body 73 is connected to an elongate nipple 21a of the same general internal and external dimensions as mandrel 21 and, with collar 70 and seal body 73, forms an extension of mandrel 21. At its lower end nipple 21a is provided with a pair of J-slots 74 which, when mandrel 21 is fully inserted in the liner string, will be opposite sub 61 which is provided with inwardly projecting J-lugs 75 which co-operate with J-slots 74 to form a releasable connection between mandrel 21 and the lower end of the liner string.

Seal body 73 is provided on its exterior with a pair of longitudinally spaced annular grooves 76—76 in which are seated resilient seal rings 77—77. The upper one of grooves 76 is in communication with the exterior of body 73 at a point above the upper one of seal rings 77 through a passage 78 and the lower one of grooves 76 is in communication with the exterior of body 73 at a point below the lower one of seal rings 77 through a passage 79. Seal rings 77 are adapted to form a slidable seal with the bore wall of the liner string as defined by bores 17a and 50a. The seal structure comprising seal

body 73 and seal rings 77—77 constitute the tell-tale seal T.

A releasable latch mechanism, designated generally by the numeral 80, forms a releasable connection between the upper end of the liner string and mandrel 21 while also providing a slidable seal between these elements. The latch mechanism comprises a collar 81 concentrically spaced about mandrel 21 and having its lower end in registration with and adapted to seat on the upper end of setting sleeve 44 of the liner packer. A pair of oppositely facing cup seals 82—82 are mounted in the upper end of collar 81 with the lips 83 of the cups in engagement with the exterior of mandrel 21 to provide a fluid-tight slidable seal between collar 81 and mandrel 21. A tubular bushing 84 is screwed into the lower end of collar 81 and serves to compressively secure cup seals 82—82 against an inwardly turned lip 85 about the upper margin of collar 81. Bushing 84 extends downwardly inside the bore of setting sleeve 44 and carries an annular packing ring 86 about its periphery to form a slidable seal with the bore wall of setting sleeve 44 near the upper end of the latter. At its lower end bushing 84 is provided with a pair of J-slots 87—87 which are positioned to receive J-lugs 72, as will be subsequently described. At points between J-slots 87—87 and seal packing 86, bushing 84 is provided with radial windows 88—88 which have latching dogs 89—89 pivotally mounted therein on pivots 90 which extend through a medial portion of the dogs, whereby to permit one end 91 of the dogs to project exteriorly of the windows when the dogs are swung downwardly about the pivots. The opposite or inner ends of the dogs have downwardly and outwardly curved end faces 92 which project into the bore of bushing 84 when ends 91 project exteriorly of the bushing and are adapted for engagement by shoulder 71 on collar 70, for purposes which will be described subsequently. Dogs 89 are normally resiliently urged to their outwardly projecting positions by means of spring-loaded thrust pins 93 which are slidably mounted in the wall of bushing 84 to project into the upper end of windows 88 into engagement with outwardly curved outer end portions 91 of dogs 89. The inner wall of setting sleeve 44 is provided with a pair of downwardly facing shoulders 94 positioned near its upper end to be engaged by outer ends 91 of the latching dogs when collar 81 is seated on the upper end of setting sleeve 44 (FIG. 1).

The above-described apparatus is employed in the following manner: The apparatus, assembled as shown in FIGS. 1 and 1A and with plug 25 removed, is run into casing C on operating pipe string 27. As so assembled, it will be seen that the lower end of mandrel extension 21a is releasably latched to the liner string by means of the engagement of J-lugs 75 in J-slots 74. Also, latch mechanism 80 will be latched to the upper end of the liner string through the engagement of dogs 89 beneath shoulders 94. Slips 64 of liner hanger 19 will be held out of engagement with expander collar 51. As so assembled, tell-tale seal T will be positioned in the bore of body 50 opposite lower seal S, and will thus be below the lowermost openings or slots 18a in screen 13. With the tool string so assembled, it may be run into the well bore, any fluid therein being displaced into the bore of mandrel 21 and its extensions and will also by-pass the upper and lower seals 15a and S, respectively. The tool string will be run through a conventional wellhead H (FIG. 7) in which is mounted a conventional blowout preventer B to provide a seal between the operating string and upper end of casing C to prevent blowouts and to close-off the upper end of the casing at the surface. Casing head H is provided with discharge nozzles N at points below blowout preventer B in accordance with conventional designs. The tool string will be run into the well to a point at which seals S and T will be somewhat above the producing formation F which is in com-

munication with the interior of the casing, through perforations P, previously provided through the wall of the casing. As illustrated, in the running-in positions of the tool parts tell-tale seal T will be positioned in the bore of liner 17 below openings 18a, thus sealing the annulus between liner 17 and mandrel 21 below screen openings 18a while cup seals 82 seals this annulus at a point above openings 18a. When the tool string has reached the position at which seals S and T are above formation F, plug 25 will be dropped through operating string 27 into seat 24 in order to close-off the bore of mandrel 21 at a point above cross-over passages 23. Wash fluid, such as water or oil, will then be pumped down operating string 27 and will flow through by-pass passages 23a in the cross-over head into the bore of casing C at a point below upper seal 15a. The fluid entering the annulus will enter port 36 of the cross-over seal structure and, due to the closures formed by seals S, T and 82, will exert pressure upon the interior faces of the seal ring 31a to expand it into sealing engagement with the wall of casing C. Lower seal S will likewise be expanded by the fluid pressure in the casing into sealing engagement with the wall of casing C and since seal S is located at a point above perforations P (FIG. 5), fluid cannot flow below this seal and even though the fluid will enter the bore of screen liner 17 through the openings therein, it cannot flow into the interior of mandrel 21 by reason of the seals formed by tell-tale seal T and cup seals 82 between liner 17 and mandrel 21 above and below screen openings 18a. Since upper seal 15a and lower seal S have been actuated, as described, the fluid cannot escape and as a result, back pressure will be built up on the surface pump. Evidence of the build-up of the pressure will apprise the operator that lower seal S is above the perforations P. Thereupon, the tool string will be lowered to position lower seal S at some point below the uppermost perforations P (FIG. 7). As soon as this occurs, fluid will flow out from above lower seal S through the uncovered perforations P into formation F and will wash away material comprising the formation adjacent the outside of casing C and will flow back through other perforations below seal S into the annulus between the liner string and the casing, whence it will be able to flow into the lower end of mandrel 21 (FIG. 7) and thence upwardly through the bore of the mandrel and its extensions to cross-over passages 23 and thence into the annulus between the tool string and casing C above upper seal 15a, from which it will then flow to the surface and out discharge nozzles N.

This washing operation will be continued with the tool string being lowered in short increments until lower seal S has been moved downwardly in casing C to a point below the perforations P (FIG. 8). At this stage of the operations, returns will again be cut-off because the fluid cannot pass below seal S and cannot, therefore, reach the interior of the mandrel. At this stage of the operations, the operating string is raised and then lowered in accordance with the conventional procedure for setting the liner hanger 19. These operations will release cage 63 and allow the liner string to move downwardly relative to slips 64 to engage expander collar 51 with slips 64 and thereby anchor the string to the casing wall and prevent its further downward movement, thereby fixing the position of lower seal S below formation F. When the tool assembly has thus been anchored to the casing, gravel packing may be begun. The previous washing of the face formation F serves to clean the latter and provide a cavity D around the perforated section of the casing which may be filled with the gravel in the subsequent packing operation.

When the liner hanger has been set, as described, the operating string will be rotated at the surface sufficiently to release the J-connection between the lower end of mandrel extensions 21a and sub 61, thereby permitting the mandrel, carrying tell-tale seal T, to be moved up-

wardly in the bore of the liner string relative to lower seal S (FIG. 9). The operating pipe will be raised sufficiently to raise tell-tale seal S to a point above the lowermost openings 18a in screen 18. When some of these openings 18a are thus exposed below tell-tale seal T, fluid, which carries the gravel, will be able to flow downwardly through the exposed openings 18a into the annular space between the liner string and mandrel 21 below tell-tale seal T and then enter the lower end of the mandrel and flow upwardly to the surface through cross-over passages 23 into the casing and out of nozzles N in casinghead H. The gravel G carried by this fluid will be deposited in cavity D and in the annular space between casing C and liner 17 above the lower seal S. This operation of elevating mandrel 21 is continued in short increments to progressively uncover additional ones of the openings 18a until all of cavity D and the portion of the annulus between casing C and the liner string have been filled with gravel to a point preferably above the upper end of formation F. In depositing gravel, as each increment of the space between seals T and S is filled, back pressure will be developed at the surface indicating that this space has been filled, thereupon tell-tale seal T will be raised by raising the operating string to uncover additional openings 18a and allowing gravel packing of successive additional intervals. As indicated, this sequence of operations is repeated until the desired amount of gravel packing has been effected, the final pack being illustrated in FIGS. 10 and 11.

When gravel packing has been completed, as described, the operating string is raised further until coupling 70 enters the bore of bushing 84 and J-lugs 72 have entered J-slots 87. When this occurs, the operating string may be rotated and the engagement of lugs 72 in J-slots 87 will transmit the rotation through dogs 89 to setting sleeve 44. The resulting rotation of the latter will produce relative longitudinal movement between the setting sleeve and packer body 40, so as to compress packer seal 43 and expand it into sealing engagement with the wall of casing C, as best seen in FIG. 11. This serves to provide a fluid-tight seal between the liner string and the casing at a point above the screen section of the liner so as to shut off escape of fluid from formation F through the annulus between the liner and the casing. Any formation fluid which will enter the bore of the liner at this stage of the operation will flow through the bore of mandrel 21 thence through cross-over passages 23 into the casing annulus and thence to the surface and out through nozzles N in the casinghead.

As soon, however, as the liner packer has been set, as described, a slight further elevation of mandrel 21, through elevation of the operating string, will bring sloping shoulder 71 into contact with the curved faces 92 of dogs 89 (FIGS. 2 and 11), forcing the latter inwardly and thereby moving out ends 91 out of engagement with shoulders 94 on setting sleeve 44. Collar 70 will then pass behind dogs 89 (FIG. 2) and continued upward elevation of the operating string will lift latch mechanism 80 out of the upper end of setting sleeve 44 (FIG. 12), thereby permitting withdrawal of the mandrel, tell-tale Seal T, latch mechanism 80, and cross-over head section 15 out of the bore of liner 17, leaving the latter in place in the well and effectively gravel packed, as shown in FIG. 12.

As the mandrel is being withdrawn from the liner string, as shown in FIG. 12, fluid circulation can be continued in the reverse direction; that is, through the casing annulus from the surface and thence through cross-over passages 23 into the bore of the mandrel and out of the lower end thereof, thence back through the annulus between the mandrel and casing C, through bypass passages 23a and into the bore of operating string 27 whence the fluid will return to the surface. This reverse circulation of fluid may be employed to wash excess gravel G off of the surface of the setting sleeve and

other parts of the liner installations so as to assure effective setting of tubing strings or the like which may subsequently be run into the well in connection with its production operation.

By employing the tell-tale arrangement heretofore described, it is found that bridging which may occur during the gravel packing operation at points above formation F or above the bottom of the latter, can be detected by the sudden back-pressure which develops when the bridge occurs. The operator will know from his previous survey of the well, the thickness of formation F and will also know the position of tell-tale seal T relative thereto at the various stages of the gravel packing. If, therefore, excessive back-pressure occurs, at any time before tell-tale seal T has moved above the top of formation F, the operator will know that bridging has occurred and he can then, by suitable manipulations of the mandrel string and the tell-tale seal, effectively wash out such bridges and re-establish the gravel packing at the proper place. Furthermore, by use of the tell-tale seal, the gravel pack can be precisely located with respect to formation F and thereby effectively assure that the gravel pack will perform the function for which it is designed.

It will be understood that various changes and modifications may be made in the details of the apparatus and in the procedural steps within the scope of the appended claims but without departing from the spirit of this invention.

What I claim and desire to secure by Letters Patent is:

1. The method of gravel packing in a well between an earth formation and liner therefor, comprising the steps of: inserting a liner having a screen portion into the well bore to position the screen portion opposite said earth formation; anchoring the liner to the well wall, positioning a first seal means below the screen portion for sealing-off the well bore between the liner and the well wall at a point below the earth formation and said screen portion; inserting a return conduit into the bore of said liner, positioning a second seal means adapted to form a slidable seal between the liner and said conduit; moving said conduit and second seal means upwardly in the bore of said liner to elevate said second seal means above said first seal means whereby to establish a fluid flow path from the exterior of the liner to the interior of the return conduit through an interval in said screen portion between said first and second seal means; introducing a gravel-carrying fluid into the annular space between the earth formation and said liner; circulating the gravel-carrying fluid from the annular space between the earth formation and said liner to said return conduit through said interval whereby to deposit gravel in said annular space while returning gravel-free fluid through said conduit to the surface; progressively elevating the second seal means relative to the first seal means to thereby progressively increase the length of said interval while containing the circulation of the gravel-carrying fluid whereby to correspondingly increase the depth of the gravel pack between the formation and the screen portion of the liner until the desired depth of gravel pack is attained; and thereafter sealing-off the annular space between the well bore and the liner at a point above said formation.

2. In a method according to claim 1, the additional step of initially washing the face of said formation by circulating gravel-free fluid through said annular space to said conduit as said first seal means is being moved downwardly past said formation during insertion of said liner.

3. The method of gravel packing in a well between an earth formation and liner therefor, comprising the steps of: inserting a liner having a screen portion into the well bore to position the screen portion opposite said earth formation; anchoring the liner to the well wall, positioning a first seal means below the screen portion for sealing-off the well bore between the liner and the well wall at a point below the earth formation and said screen portion; inserting a return conduit into the bore of said liner,

positioning a second seal means adapted to form a slidable seal between the liner and said conduit; moving said conduit and second seal means upwardly in the bore of said liner to elevate said second seal means above said first seal means whereby to establish a fluid flow path from the exterior of the liner to the interior of the return conduit through an interval in said screen portion between said first and second seal means; introducing a gravel-carrying fluid into the annular space between the earth formation and said liner; circulating the gravel-carrying fluid from the annular space between the earth formation and said liner to said return conduit through said interval whereby to deposit gravel in said annular space while returning gravel-free fluid through said conduit to the surface; progressively elevating the second seal means relative to the first seal means to thereby progressively increase the length of said interval while continuing the circulation of the gravel-carrying fluid whereby to correspondingly increase the depth of the gravel pack between the formation and the screen portion of the liner until the desired depth of gravel pack is attained; thereafter sealing-off the annular space between the well bore and the liner at a point above said formation; and withdrawing said conduit and said second seal means from the well bore.

4. In a method according to claim 3, the additional step of reversing the flow of washing fluid down through said conduit to the interior of the well bore and back to the surface as the conduit is being withdrawn from the liner to wash out the interior thereof.

5. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer positioned above the screen section for sealing between the liner and the wall of the well bore, a first seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel open at its lower end and extending through the bore of the liner string and slidable therein, a second seal means mounted about the mandrel above its lower end to seal between the mandrel and the bore wall of the liner, the second seal means being slidable with the mandrel between points above and below said screen section whereby to open screen intervals of varying lengths between said first and second seal means to passage of fluid from the well bore to the bore of the mandrel, an upper seal member mounted on the liner string above the screen section to form a slidable seal about the mandrel, and means mounted on said mandrel above said upper seal member for directing gravel-carrying fluid into the annulus between the liner and wall of the well bore.

6. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer positioned above the screen section for sealing between the liner and the wall of the well bore, a first seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel open at its lower end and extending through the bore of the liner string and slidable therein, a second seal means mounted about the mandrel above its lower end to seal between the mandrel and the bore wall of the liner, the second seal means being slidable with the mandrel between points above and below said screen section whereby to open screen intervals of varying lengths between said first and second seal means to passage of fluid from the well bore to the bore of the mandrel, an upper seal member mounted on the liner string above the screen section to form a slidable seal about the mandrel, means mounted on said mandrel above said upper seal member for directing gravel-carrying fluid into the annulus between the liner and wall of the well bore, and latch means re-

leaseably securing said upper seal member to the liner string, said latch means being releasable by pre-determined upward movement of the mandrel to thereby release the mandrel for withdrawal from the liner string.

7. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer positioned above the screen section for sealing between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel open at its lower end and extending through the bore of the liner string and slidable therein, a second seal means mounted about the mandrel above its lower end to seal between the mandrel and the bore wall of the liner, the second seal means being slidable with the mandrel between points above and below said screen section whereby to open screen intervals of varying lengths between said first and second seal means to passage of fluid from the well bore of the mandrel, an upper seal member mounted on the liner string above the screen section to form a slidable seal about the mandrel, and means for directing gravel-carrying fluid into the annulus between the liner and wall of the well bore, said last-mentioned means comprising a cross-over head for connecting the upper end of the mandrel to a fluid-supply pipe and including cross-over passages arranged to direct fluid from said supply pipe to said annulus below the cross-over head and to further direct the fluid returning through the screen section and the bore of the mandrel to the well bore above the cross-over head.

8. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer positioned above the screen section for sealing between the liner and the wall of the well bore, a first seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel open at its lower end and extending through the bore of the liner string and slidable therein, a second seal means mounted about the mandrel above its lower end to seal between the mandrel and the bore wall of the liner, the second seal means being slidable with the mandrel between points above and below said screen section whereby to open screen intervals of varying lengths between said first and second seal means to passage of fluid from the well bore to the bore of the mandrel, an upper seal member mounted on the liner string above the screen section to form a slidable seal about the mandrel, means mounted on said mandrel above said upper seal member for directing gravel-carrying fluid into the annulus between the liner and wall of the well bore, and a releasable connection securing the mandrel to the liner string in a relation to initially position said second seal means below said screen section and operable by manipulation of the mandrel to release the latter for upward movement relative to the liner string.

9. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer positioned above the screen section for sealing between the liner and the wall of the well bore, a first seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel open at its lower end and extending through the bore of the liner string and slidable therein, a second seal means mounted about the mandrel above its lower end to seal between the mandrel and the bore wall of the liner, the second seal means being slidable with the mandrel between points above and below said screen section whereby to open screen intervals of varying lengths between said first and second seal means to passage of fluid from the well bore to the bore of the mandrel, an upper seal member mounted on the liner string above

the screen section to form a slidable seal about the mandrel, means mounted on said mandrel above said upper seal member for directing gravel-carrying fluid into the annulus between the liner and the wall of the well bore, latch means releasably securing said upper seal member to the liner string, said latch means being releasable by pre-determined upward movement of the mandrel to thereby release the mandrel for withdrawal from the liner string, and a releasable connection securing the mandrel to the liner string in a relation to initially position said second seal means below said screen section and operable by manipulation of the mandrel to release the latter for upward movement relative to the liner string.

10. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer structure positioned above the screen section and including a resilient seal ring for sealing between the liner and the wall of the well bore, a lower seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel extending through the bore of the liner string and slidable therein, a seal element mounted on the mandrel to form a slidable seal between the mandrel and the bore of the liner string, an upper seal member mounted on the upper end of said liner string and forming a slidable seal about the mandrel above said screen section, lower latch means releasably connecting the mandrel to the liner string, said lower latch means being releasable by manipulation of the mandrel to permit longitudinal movement of the mandrel relative to the liner string, a cross-over head connected to the mandrel above said upper seal member, said cross-over head including an outer shell concentrically positioned about the mandrel and connectible at its upper end to an operating pipe string, cross-over passages providing fluid communication between the bore of the mandrel and the exterior of said shell, annular seal means about the shell adapted to seal between the shell and the wall of the well bore below the cross-over passages, and removable means for closing the bore of the mandrel at a point above said cross-over passages.

11. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer structure positioned above the screen section and including a resilient seal ring for sealing between the liner and the wall of the well bore, a lower seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel extending through the bore of the liner string and slidable therein, a seal element mounted on the mandrel to form a slidable seal between the mandrel and the bore of the liner string, an upper seal member mounted on the upper end of said liner string and forming a slidable seal about the mandrel above said screen section, lower latch means releasably connecting the mandrel to the liner string, said lower latch means being releasable by manipulation of

the mandrel to permit longitudinal movement of the mandrel relative to the liner string, a cross-over head connected to the mandrel above said upper seal member, said cross-over head including an outer shell concentrically positioned about the mandrel and connectible at its upper end to an operating pipe string, cross-over passages providing fluid communication between the bore of the mandrel and the exterior of said shell, annular seal means about the shell adapted to seal between the shell and the wall of the well bore below the cross-over passages, and removable means for closing the bore of the mandrel at a point above said cross-over passages, said packer structure being of the screw-set type operable by relative rotation between the mandrel and the liner to expand said seal ring.

12. Gravel packing apparatus, comprising, a liner string insertable in a well bore, said liner string including: a tubular liner having a screen section, a packer structure positioned above the screen section and including a resilient seal ring for sealing between the liner and the wall of the well bore, a lower seal means positioned below the screen section to seal between the liner and the wall of the well bore, and anchor means for anchoring the liner string to the wall of the well bore; a tubular mandrel extending through the bore of the liner string and slidable therein, a seal element mounted on the mandrel to form a slidable seal between the mandrel and the bore of the liner string, an upper seal member mounted on the upper end of said liner string and forming a slidable seal about the mandrel above said screen section, lower latch means releasably connecting the mandrel to the liner string, said lower latch means being releasable by manipulation of the mandrel to permit longitudinal movement of the mandrel relative to the liner string, a cross-over head connected to the mandrel above said upper seal member, said cross-over head including an outer shell concentrically positioned about the mandrel and connectible at its upper end to an operating pipe string, cross-over passages providing fluid communication between the bore of the mandrel and the exterior of said shell, annular seal means about the shell adapted to seal between the shell and the wall of the well bore below the cross-over passages, and removable means for closing the bore of the mandrel at a point above said cross-over passages, said packer comprising a tubular body carrying said seal ring about its exterior and connected directly to the liner, a tubular setting sleeve concentrically positioned about the body for axial engagement with the seal ring and threadedly connected to said body whereby rotation of the setting sleeve relative to the body will radially expand said seal member into sealing engagement with the well wall, and means forming a rotational drive connection between the mandrel and the setting sleeve.

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