International Progress Report

IPR-01-53

Äspö Hard Rock Laboratory

TRUE Block Scale project

Reconciliation of the March'99 structural model and hydraulic data

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October 1999

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Report no.	No.
IPR-01-53	F56K
Author	Date
Doe	99-10-01
Checked by	Date
Approved	Date
Christer Svemar	02-08-23

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Keywords: Hydraulic assessment, reconciliation, structural model transmissivity, visualization

Abstract

This report reviews the March'99 structural model (Hermanson, 1999) and the hydraulic data from flow logs, build-up tests, and the spring 1999 tracer Pre-test program. The latter includes both pressure interference tests and tracer dilution tests.

The hydraulic data review largely confirms the major features of the March'99 structural model. Structures #10, #19, #20, and #6 produce hydraulic responses that are consistent with the structural model. Structure #13 appears in KA2563A and KI0023B, but it may not continue southeastward to KI0025F02 or KI0025F. Hermanson proposed two new structures which provide flow between Structures #13 and #20, the two major, sub-parallel structures of the central portion of the TRUE Block Scale volume. Hermanson named these new structures #21 and #22. Structure #22 appears in the drilling responses to KI0025F02, and likely appears in KI0023B, but does not extend to KA2563A. Additional fractures provide connections between Structures #20 and #6 using Structure #22 as part of the path. Structure #21 is not a clearly defined. The critical monitoring interval for assessing Structure #21 is KI0023B:P3. Tracer dilution tests provide data consistent with a conductor along Structure #21, but pressure interference responses appear too weak to support this part of the model. Additional connections between Structures #13 and #20 likely exist, and evidences for some additional possible conductors are discussed.

Sammanfattning

Denna rapport granskar strukturmodell Mars ’99 (Hermanson, 1999) och hydrauliska data från flödesloggningar, tryckuppbyggnadstester och spårförsöksprogram under våren 1999. Det senare inkluderar både tryckinterferenstester och utspädningsmätningar.

Genomgången av erhållna hydrauliska data bekräftar till stor del de stora dragen i strukturmodell Mars ’99. Strukturerna #10, #19, #20 och #6 visar hydrauliska responser som är överensstämmande med strukturmodellen. Struktur #13 framträder i KA2563A och KI0023B, men fortsätter ej nödvändigtvis åt sydost till KI0025F02 och KI0025F. Hermanson föreslog två nya strukturer vilka förmedlar flöde mellan struktur #13 och #20, de två största, subparallella strukturerna i den centrala delen av TRUE Block Scale volymen. Hermanson gav dessa två strukturer benämningen #21 och #22. Struktur #22 framträder i tryckresponserna vid borrning av KI0025F02 och uppträder sannolikt även i KI0023B, men sträcker sig inte ända till KA2563A. Ytterligare sprickor förser förbindelser mellan Struktur #20 och #6 genom att använda #22 som transportväg. Struktur #21 är inte tydligt definierad och den kritiska borrhålssektionen för fastställning av strukturen är KI0023B:P3. Spårämnesförsök ger data som överensstämmer med en hydraulisk ledare längs Struktur #21, men tryckinterferensresponser framträder för svagt för att stöda den delen av modellen. Ytterligare förbindelser med mellan #13 och # 20 existerar troligtvis och bevis för några ytterligare möjliga hydrauliska ledare diskuteras.

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1. Purpose

This report describes a program of hydraulic data analyses to verify the March 1999 structural model (Hermanson, 1999) of the TRUE Block Scale experimental site. The analyses take advantage of information provided by the most recent borehole, KI0025F02 as well as the results of a program of pressure interference tests and tracer dilution tests that Geosigma AB performed to provide data to help design the main tracer testing phase for the TRUE Block Scale program (the Pre-Test or PT program, Andersson et al., 1999)).

The major objectives of this work are the following:

- Verification of March'99 structural model

- Suggestions of revisions to structural model based on inconsistencies of the model and the hydraulic data

- Production of an overlay to the March '99 model where the hydraulic significance of the structures is highlighted.

- Tabulation of transmissivities associated with the significant structures

The structural model of the TRUE-block scale site has continuously evolved with the drilling, testing, and exploration of the True Block Scale volume. By the time the most recent borehole, KI0025F02, was drilled, the major geologic and hydrologic structures of the block were known with sufficient confidence to allow accurate predictions of the locations and relative hydraulic significance of these major structures. The major hydraulic structures of the site consist of several northwest trending fractures and fracture zones. These hydraulically significant zones are a subset of a larger family of geologically identified structures. Prior to the development of the March’99 model these structures were identified, in order of appearance from the borehole collars, as #5, #7, #6, #20, #13, #19, and #10. The location of these structures is shown in map view in Figure 1. Structures #5, #6,and #7 were sufficiently transmissive to require grouting to assure borehole stability, and were thus not considered as targets for the main phase of tracer testing.

The main goal of the TRUE-block scale program has been the testing of networks of features rather than single features, which was the focus of another phase of the TRUE program. Structures 19 and 10 were too isolated to form a significant fracture network. Hence the focus of the tracer-testing program moved to the major structures of the central portion of the True Block Scale volume, specifically Structures #20, #13, and #6. Structures #20 and #13 are sub-parallel, but were known from inference tests to be connected by conducting fractures that were not prominent enough to have been assigned numbers. A major goal of geologic analyses after the completion of KI0025F02 was to identify in more detail the fractures that connect these numbered structures. Based on analyses of the flow logs and geologic logs, Hermanson (1999) proposed two possible structures, which had more northerly trends than #13 and #20. These potential cross-cutting structures were given the designations #21, and #22 (Figure 1). Each of these structures was proposed on the basis of only two intersections, and there were no hydraulic interference data to corroborate their existence as conductive structures. Hence, one goal of the Pre-test program was to provide hydraulic data to test the March’99 additions to the structural model.

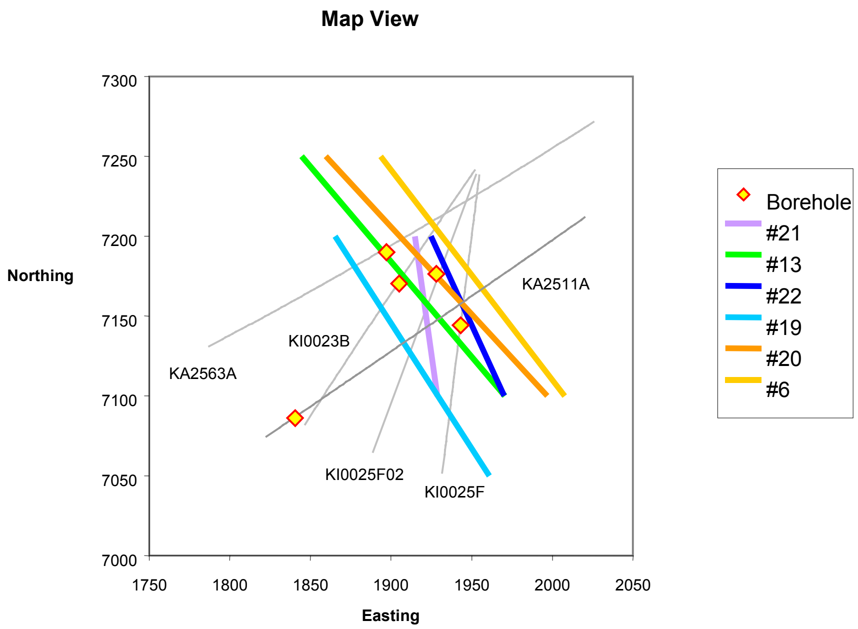


Figure 1. *Map view of conducting structures in March '99 structural model. Diamonds show intercepts of the boreholes with a horizontal plane at Depth= -480 meters. Please note, this map view shows the relative locations of the structures and takes no account of terminations. Section 6 and Figure 19 present the discussion of terminations. To emphasize the core area of the TRUE Block Scale Volume, Structures #7 and #10 are not shown. These are however shown in Figure 19.*

2. Data Sources

Several sources of hydraulic data were used for this work.

Pressure monitoring during drilling provides a significant source of hydraulic data for analyzing the structural model. The drilling data have two types. First, the drilling crew took measurements of the flow from the hole every time the core was removed, which was approximately every three meters of drilling. Passage of each conducting structure added that structure's contribution to the total outflow, thus each increase of flow with depth indicated the approximate location of a conducting fracture.

The second form of monitoring information during drilling used the pressure measurement network in previously drilled boreholes. Most intersections of conducting structures caused pressure drops in those piezometer intervals that were connected to that conducting structure. The pattern of pressure responses provided a means of mapping the conducting structures across the True Block Scale volume. Previous studies of the drilling responses helped to define and confirm the hydraulically active components of the structural model (Doe and Fox 1999). For this study we added the drilling data from KI0025F02.

Flow logs are measurements of the inflow to boreholes, usually with the holes at atmospheric pressure conditions. The flow logging methods have evolved considerably during the TRUE-block scale exploration program. The initial boreholes were partially logged using double packer systems with 5-m spacings (Gentzschein, 1997, 1998a,b). This method was applied to boreholes KI0025F, KA2365A, and KA2511A. While the packer method was effective, its 5-m resolution was not always sufficient to identify the specific geologic features responsible for the flow.

Later phases of the program introduced the Posiva logging system that employs a downhole thermal-pulse flow meter. The flow meter measures over a 1-m interval, but unlike packer systems, its flexible seals allow it to be moved up the hole while continuously taking flow readings. This continuous logging allows more precise definition of flowing features, and, when used in combination with single point resistivity measurements often pinpoints to a resolution of 0.1 meters. The Posiva logging tool was used on KI0025F02 and on KA2563A and KA2511A when their packers had been removed to reconfigure the piezometers (Rouhiainen and Heikkinen, 1999 a,b) .

Solexperts (Adams, 1998, Adams et al., 1998, 1999) performed pressure build-up tests in two boreholes – KI0023B and KI0025F02. These tests targeted probable conductors in these two holes using short (1-2.5m) packer spacings. The buildup tests isolate a flowing feature after it has been flowing into the borehole for some period of time at a specified head drop. Shutting off a given feature's flow results in a pressure build-up that can be analyzed using transient well-test methods to provide hydraulic properties. Unlike flow-logging methods, transient tests can "see" beyond the local transmissivity field within the conductor to provide a transmissivity values that better represents the feature as whole.

Pressure interference tests provide the ultimate mapping and confirmation of the conducting network. A major phase of pressure interference testing was completed after KI0023B was drilled (Andersson et al, 1998). However, this report relies mainly on the interference data from the Pre-test program. The Pre-test program includes an additional hole, KI0025F02. Also, the piezometer array in KA2563A was improved to eliminate some spurious connections and to include the main hydraulic intersections of Structure #19. The Pre-test (PT) program (Andersson et al, 1999) consists of four tests with tracer dilution measurements (PT-1 to PT-3) and selected cross-hole tracer injections to identify suitable intervals for later, more intensive, testing (PT-4). This report uses data from Pre-tests 1,2, and 3, which pumped from Structures #13, #21, and #20 respectively. Geosigma also performed a series of short-term interference tests in the autumn of 1998 using all of the sections in KI0025F02 as source (except for zone 4). These tests were very useful for determining details of the connections among Structures #6, #13, #20 and #22.

Tracer dilution tests involve tracer injections at low injection rates into a selected piezometer interval under near-static conditions. The dilution of tracer with time is a measure of the groundwater flux through the test interval under either static conditions or when another zone is being pumped. Dilution tests provide a very useful complement to interference tests. Those intervals that are well connected to the pumping source intervals should experience an increase in flux due the pumping. A change in the dilution rates before and after pumping provides an indication of connectivity to the pumping source. Generally these changes involve increased flux, unless the pumping is counter-acting a strong, oppositely directed natural flux through the interval. The tracer dilution data used for this report came from the recently performed Pre-tests (Andersson et al., 1999).

3. Approach

The first activity we undertook for the reconciliation exercise was the analysis the drilling data from KI0025F02. These data were very relevant to the identification of Structure #22. One difficulty in recognizing Structures #21 and #22 was that they appeared within a few meters of other conducting structures in each of the holes where their locations were hypothesized. An exception was the intersection of Structure #22 with KI0025F02. Were this structure present, it should have created drilling responses at about 67-m depth, or about 7 meters before Structure #20, which is the dominant structure in the central portion of the True Block Scale volume.

Figure 2 shows the pressure responses to KI0023B to the drilling of KI0025F02. The plot records pressure in each piezometer interval with time, along with the drilling depth plotted against the secondary axis of the chart. For reference, vertical lines provide the times and depths where the drillers recorded significant changes in flow from the hole. The first major pressure responses appear with the intersection of Structure #7, followed by a weaker response to intersecting Structure#6. At about 67 meters, there is a double decline in pressure reflecting the intersection of two conducting features. The first of these is a conductor at the predicted location of Structure #22 and the second is the intersection with Structure #20. The pressure response data provide two significant observations about the hydraulic network. First, it confirms the position of Structure #22. Second, the pattern of responses follows the path of Structure #20 and other connected features, thus showing that Structure #22 is part of a larger system that is hydraulically dominated by Structure #20.

The second activity we pursued was an analysis of the drawdown behaviors during the three pre-tests. We used two plotting methods for the data. The first used Geosigma's indicator plot of normalized drawdown (head change divided by source pumping rate) against the delay time of pressure responses, normalized by the square of distance of the observation point from the source. In a rough sense this compares transmissivity, which is the flow capacity, with the diffusivity, which measures the speed of pressure transmissions. As diffusivity is the ratio of transmissivity and storage, the two axes are generally negatively correlated. In an ideal continuum, all pathways would have the same diffusivity, hence a perfect continuum would appear along a line parallel to the drawdown axis in Geosigma's indicator plot.

A second plotting method is the distance-drawdown plot. This is a logarithmic plot of drawdown on one axis against time divided by inverse-distance squared on the other. Although this uses the same units for the x-axis as the Geosigma plot, the time in this case is a time late in the test when the drawdowns approach relatively stable values. Hence, this plot indicates drawdown values versus distance at a particular, late time value. Because the distance appears in the denominator of the x-argument, distance increases towards the origin and decreases with larger x values. Hence the point with the largest x-value is the drawdown at the pumping well itself.

The advantage of the distance drawdown plot is that it can be used for type-curve analysis, as the same curves that describe the variations in drawdown versus time at a single point, also describe drawdown at all points at the same value of time. If the rock medium is a perfect continuum, all points on distance drawdown plot will lie on the type curve. If there are multiple conducting features, the drawdowns will tend to cluster at particular drawdown values or follow separate trends. The set of points with the highest drawdown values will generally be part of the system that is providing the major portion of the water to the pumping source. Other conducting features, or observation points that are poorly connected to the source well will cluster at lower drawdown values than the main conductor. Figures 3 to 5 are distance-drawdown plots of the results of the three Pre-tests.

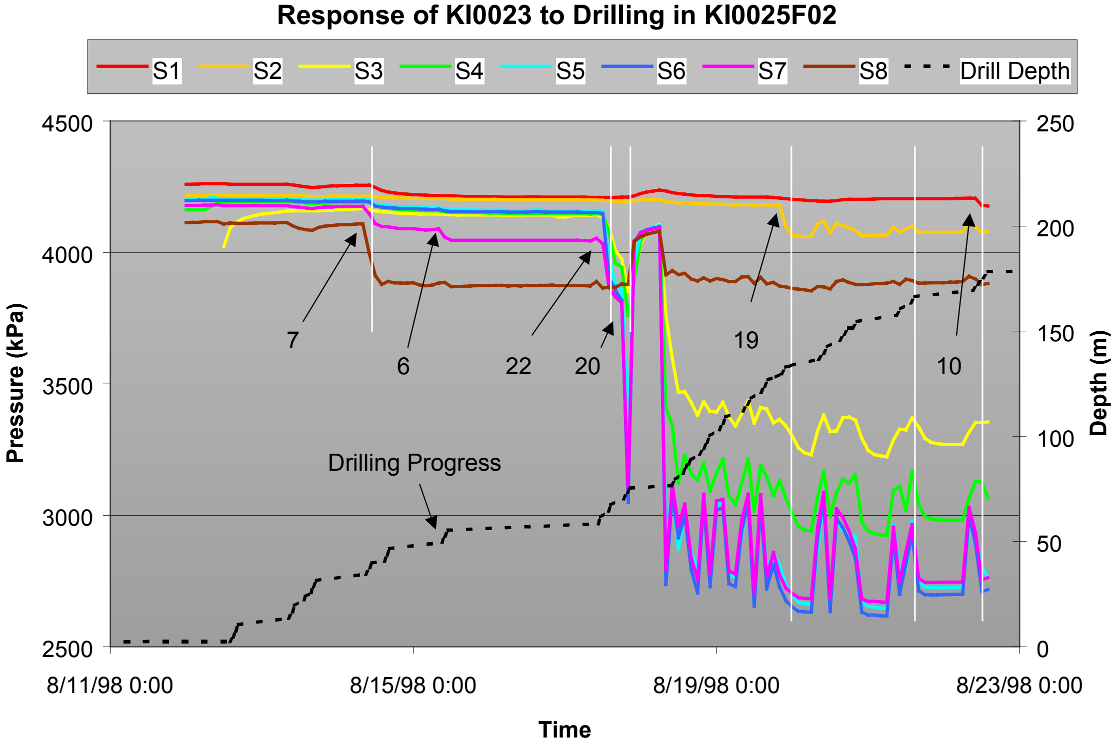
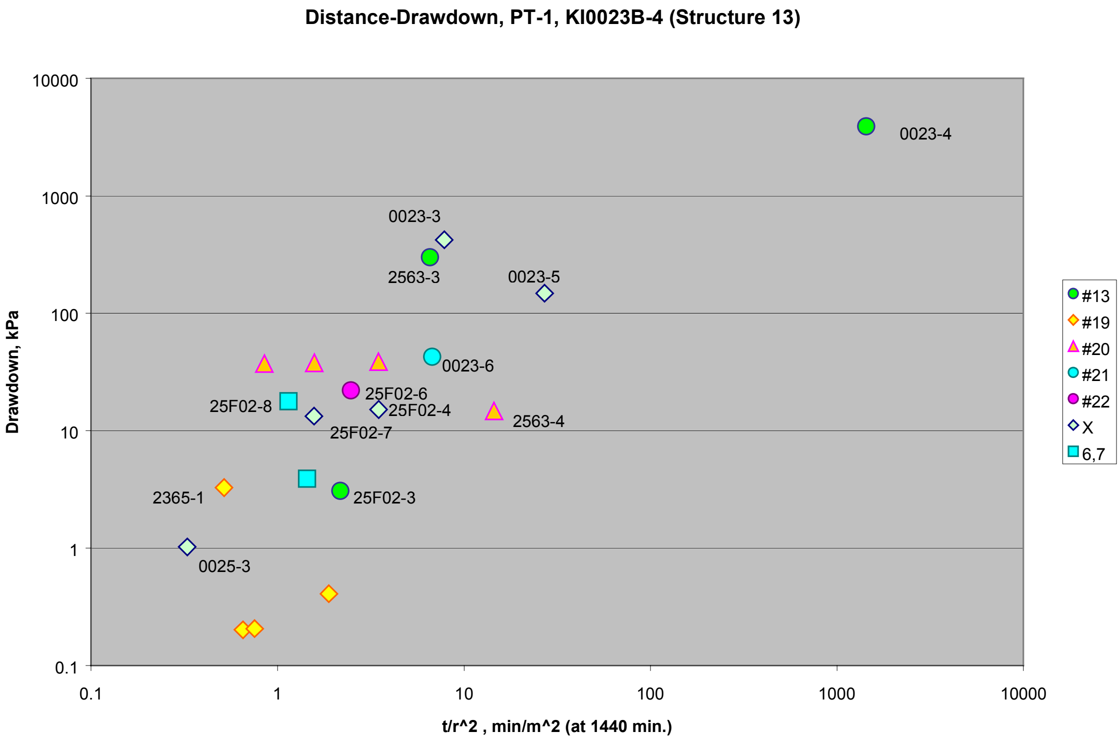


Figure 2. *Pressure responses versus time in piezometer intervals of KI0023B during the drilling of KI0025F02.*

Intersections of KI0025F02 with structures are labeled and indicated with arrows. White lines are approximate depths and times of inflow changes to KI0025F02. Right vertical axis shows the drilling depth. Note separate responses of #22 and #20.



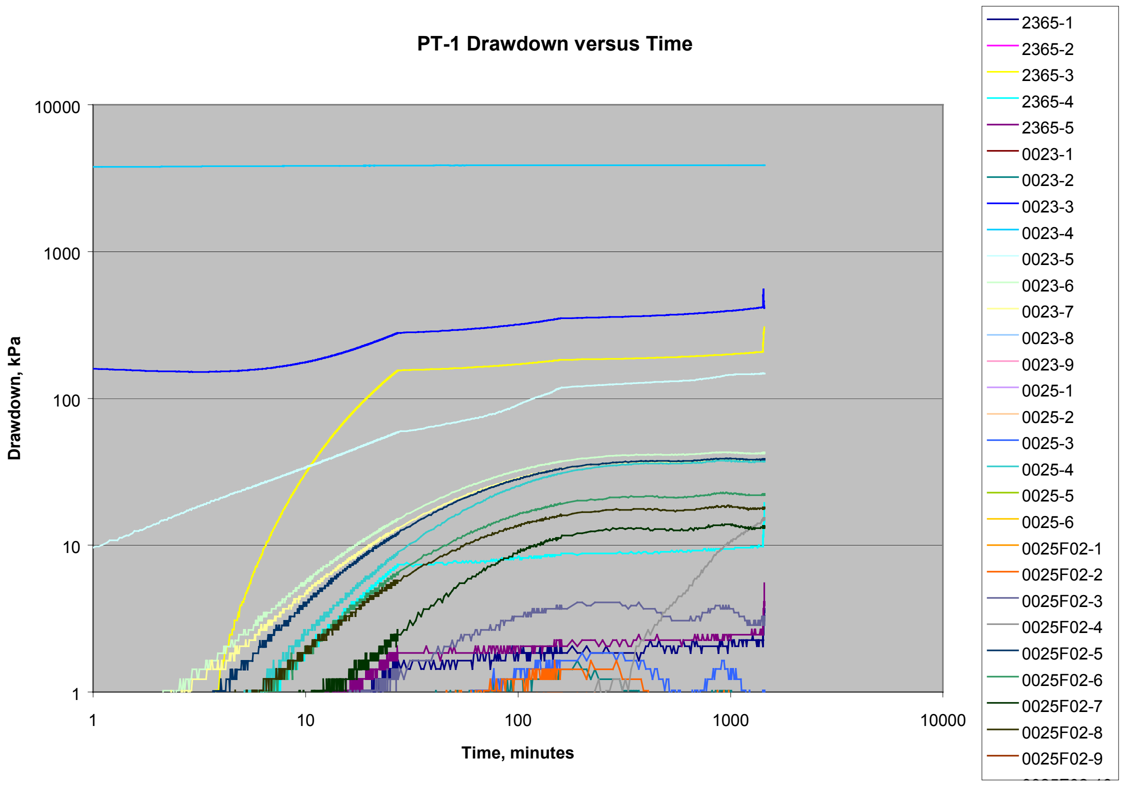
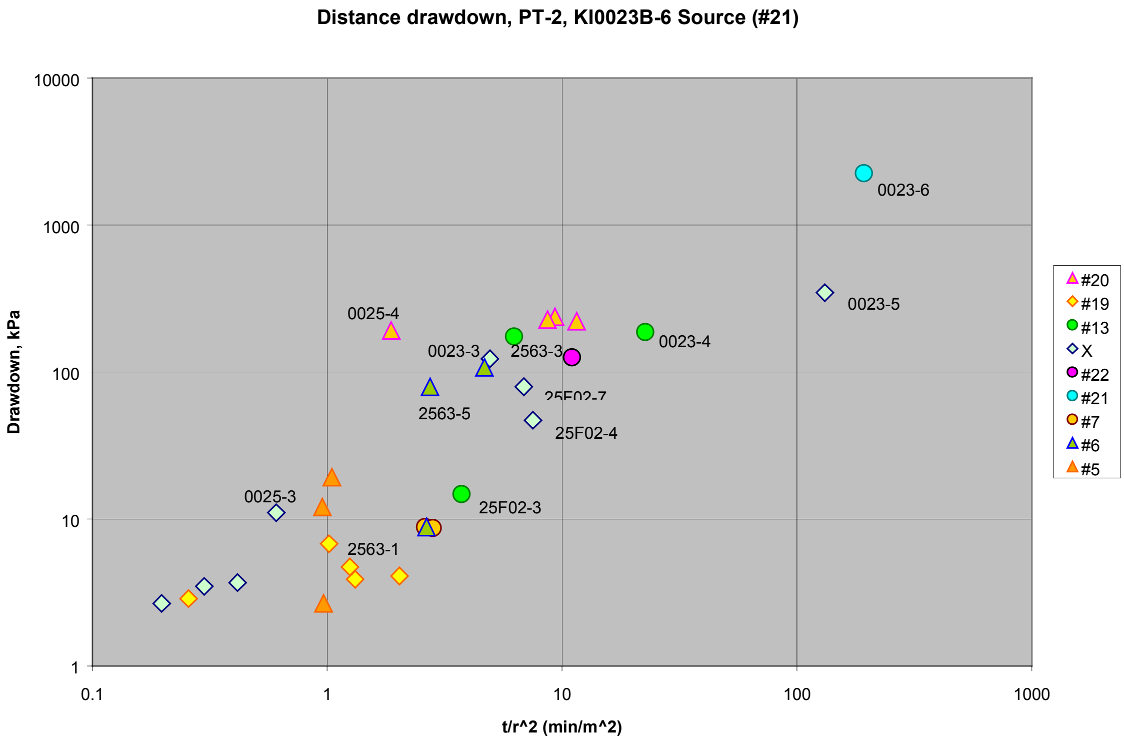


Figure 3. *Pre-Test PT-1: Top: Distance-drawdown plot for end of test. Pumping source is point in upper right. Symbols are grouped by structure. Bottom: Drawdown versus time.*



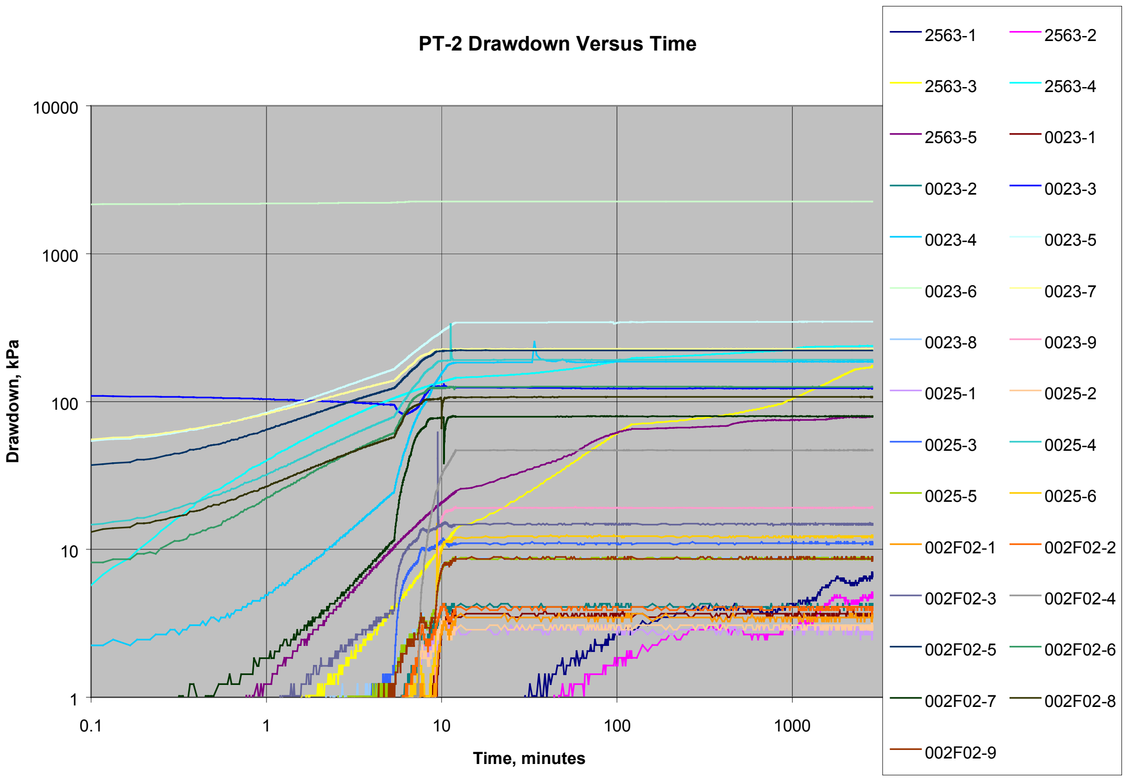
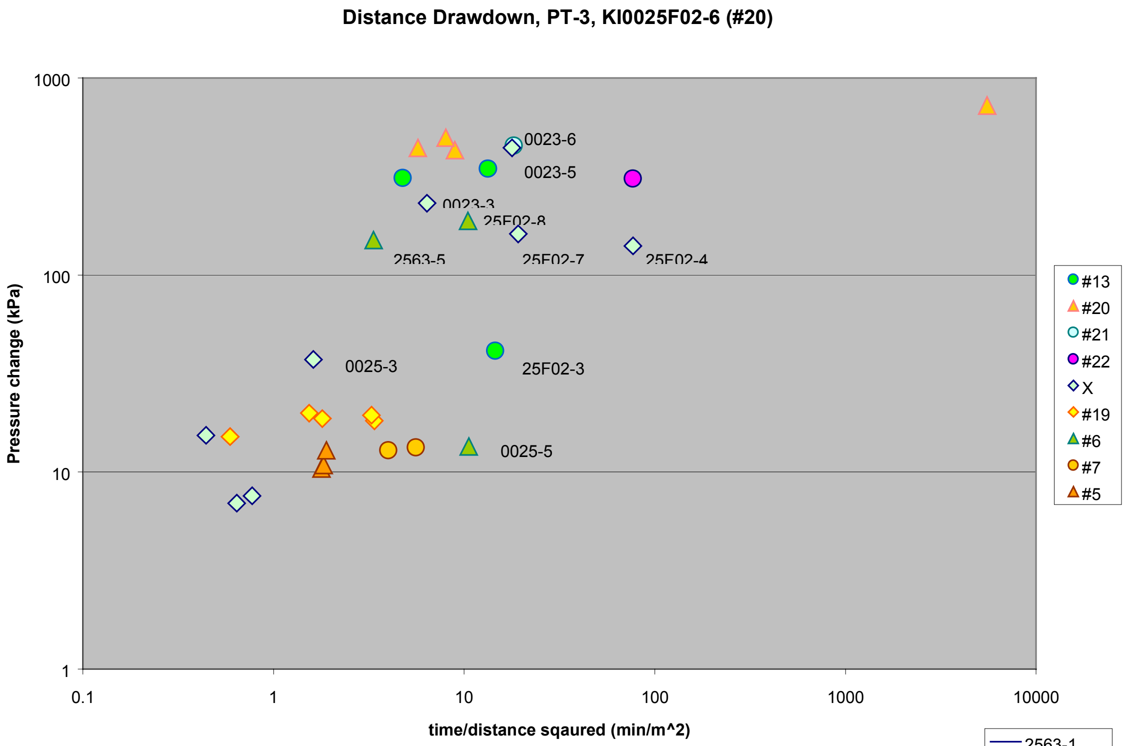


Figure 4. *Pre-Test PT-2: Top: Distance-drawdown plot for end of test. Pumping source is point in upper right. Symbols are grouped by structure. Bottom: Drawdown versus time.*



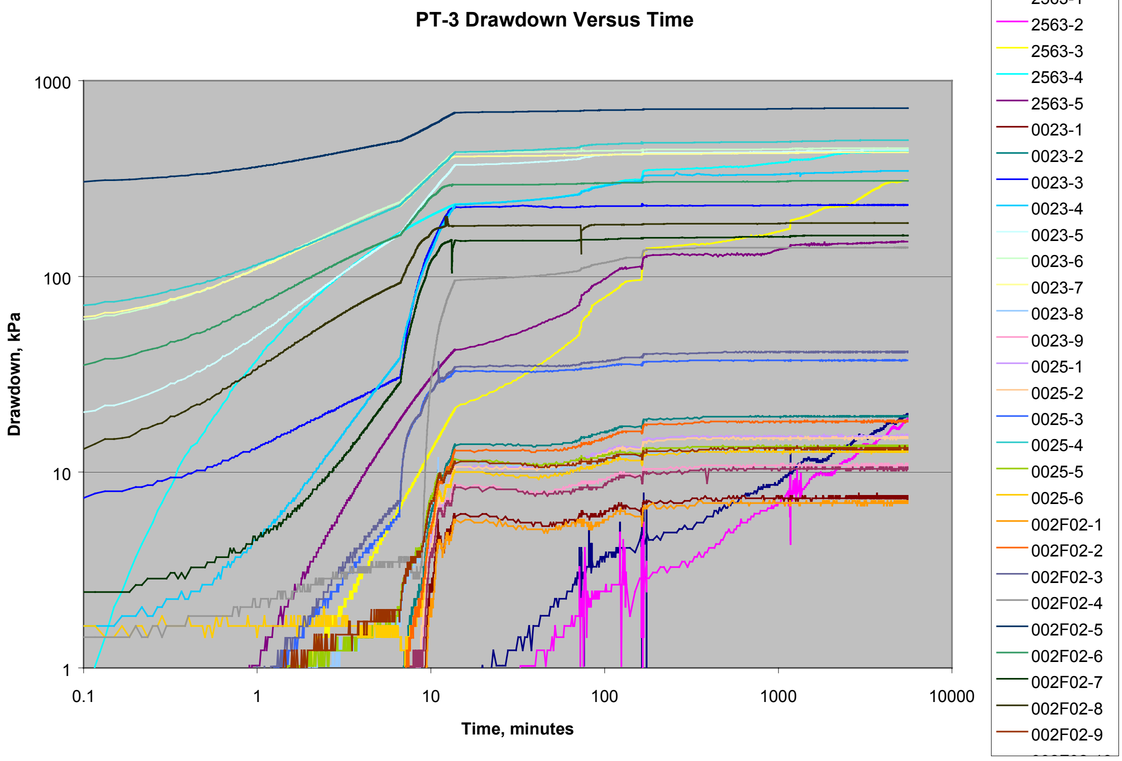


Figure 5. *Pre-Test PT-3: Top: Distance-drawdown plot for end of test. Pumping source is point in upper right. Symbols are grouped by structure. Bottom: Drawdown versus time.*

4. Visualization of Hydraulic Data

An important part of this exercise is the compilation and display of the hydraulic data in a form that can be compared with the structural model. Figure 6 provides a comparison of the hydraulic data and the structural model. The plot shows the hydraulic data in bar chart form along parallel lines. The length axes for each borehole are adjusted so that Structure #20 is located at zero length in each hole. As Structure #20 is a subvertical feature, this adjustment brings the four holes into approximate alignment. Five-meter flow log data area available for holes KI0023B and KI0025F. These are the only flow data in the latter hole except for drilling responses. Posiva flow log data appear as red bars for boreholes KI0025F02 and KA2563A. The flow data from the build-up tests, normalized to atmospheric borehole, appear for KI0023B. The locations of flows encountered during drilling appear as triangles below the line for each hole. These may be imprecise in their depths, as the flows generally cannot be resolved within the length of a core run. The flow-log and pressure build-up data are adjusted to common units of ml/hr for a head difference of 400-m, and bar heights are proportional to the flow values. The cut off flow for inclusion in the figure was 0.1 l/min.

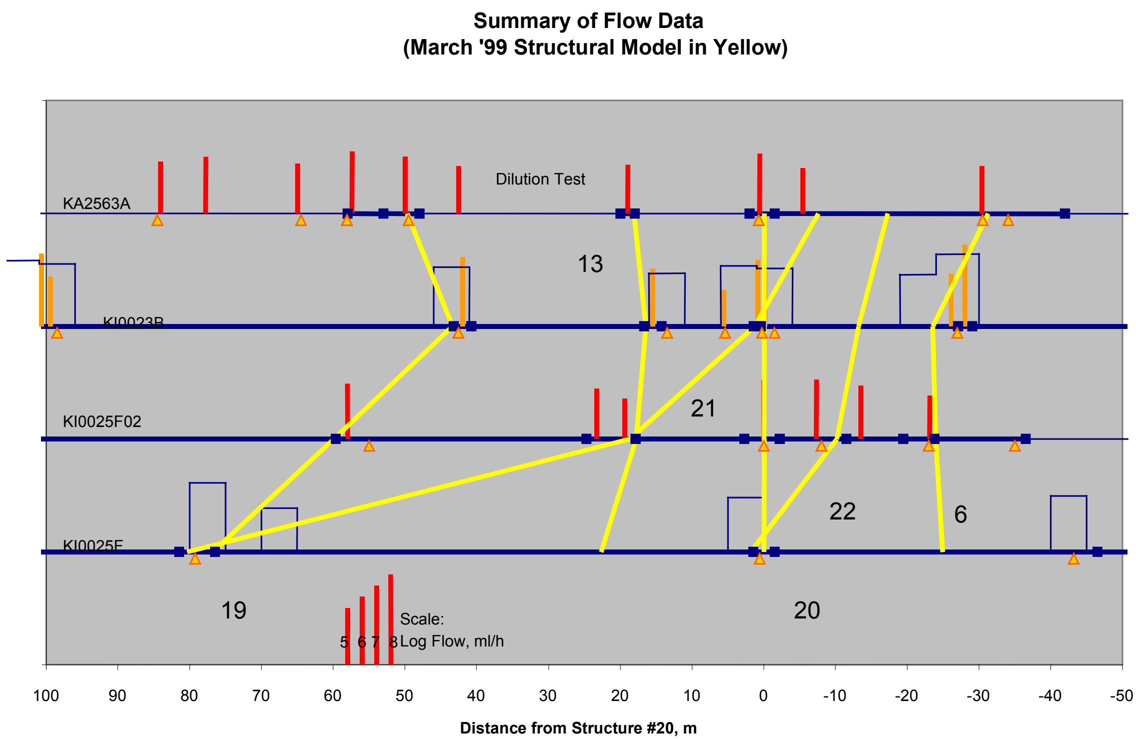


Figure 6. *Summary of flow data from borehole testing and monitoring.*

Triangles show points of inflow and pressure response during drilling. Heavy lines on borehole axes indicate monitored piezometer intervals.

Data from flow logs and tests are normalized to an equivalent inflow rate in ml/h under atmospheric borehole pressure conditions. Data are shown in log scale according to the scale at the bottom of the figure.

Red bars show Posiva flow log data. Orange bars are pressure buildup tests. Blue outline histograms are 5-m packer tests. The data are shown as equivalent inflows in ml/h for the boreholes at atmospheric pressure. Yellow lines show the conducting structures in the March '99 structural model. Boreholes are shown schematically as parallel lines with thicker lines showing the monitored intervals. Distances on the x-axis are measured from the intersection with Structure #20 in each hole.

5. Hydraulic Assessment of Features in the March '99 Structural Model

5.1 Structure #13

Structure #13 is one of the key structural and hydraulic features of the central portion of the True Block Scale volume. Pre-test 1 used Structure #13 as a source withdrawing from piezometer zone KI0023B:P4. An inspection of the distance drawdown plot provides insight to the structural geometry of the conductive portions of the structure.

As discussed above, the continuity or discontinuity of the flow system can be inferred from the pattern of the drawdowns around the pumping source. The drawdowns cluster in three major groups in this test. The first group has drawdowns greater than 100 kPa and represent well-connected portions of Structure #13, specifically KA2563-4, and the monitoring intervals adjacent the source interval.

The second group of responses has drawdowns between 10 and 100 kPa. Mostly these intervals are parts of the Structure #20 flow system. This system includes Structures #21 and #22, as well as some portions of Structure#6, though the latter may be due in part to a short-circuit between Structure #20 and Structure #6 in borehole KI0023B:P7. Short-circuits in piezometer intervals are discussed in more detail in section 6.

The remaining intervals form a third group or set of groups that have drawdowns less than 100 kPa. These zones come from the other structures including #19, #10, and #5. Included in this category is KI0025F02:P3, an interval with low drawdown responses to withdrawaals from Structure #13 despite containing conductors that structural model attributes to Structures #13 and #21. KI0025F does not contain any intervals that have strong or moderate pressure responses to pumping in Structure #13.

The responses of KI0025F02:P3 are very important for the hydraulic model. The March'99 structural model also has Structure #21 intersecting in this zone. It is significant that this section responds weakly to all three Pre-tests (Figures 3-5), and even more weakly to pumping in Structure #13 than to Structures #20 and #21. The reasons for these responses are discussed in the following paragraphs and in the discussion on Structure #21. The weak response is also shown in the drawdown map of PT-1 (Figure 8) which shows stronger drawdowns in piezometer intervals associated with the Structures #20, #21, and #22 than in KI0025F025:P3, which contains Structure #13.

An alternate explanation for the low drawdown in KI0025F02:P3 is a boundary effect. A boundary effect that would cause a reduced drawdown would imply a constant-pressure rather than a no-flow boundary. Constant-pressure boundary effects imply that the interval contains a second conductor with higher storage and conductivity than Structure #13 such that it provides a stronger flow than we would expect from Structure #13 alone.

We can discriminate between these two possible explanations, poor connection versus boundary effect by checking the dilution data. If the connection is poor, we should see low-flow results in tracer dilution test from this interval, while a boundary effect would show stronger dilution. Figure 7 shows the dilution test from which we may conclude that there is a Structure #13 connection and the low drawdown may be a boundary effect. There were negative dilution results from other parts of the Structure #20-21 network, but this may reflect the low pumping rate in Structure #13 relative to the higher flow capacity of Structure #20.

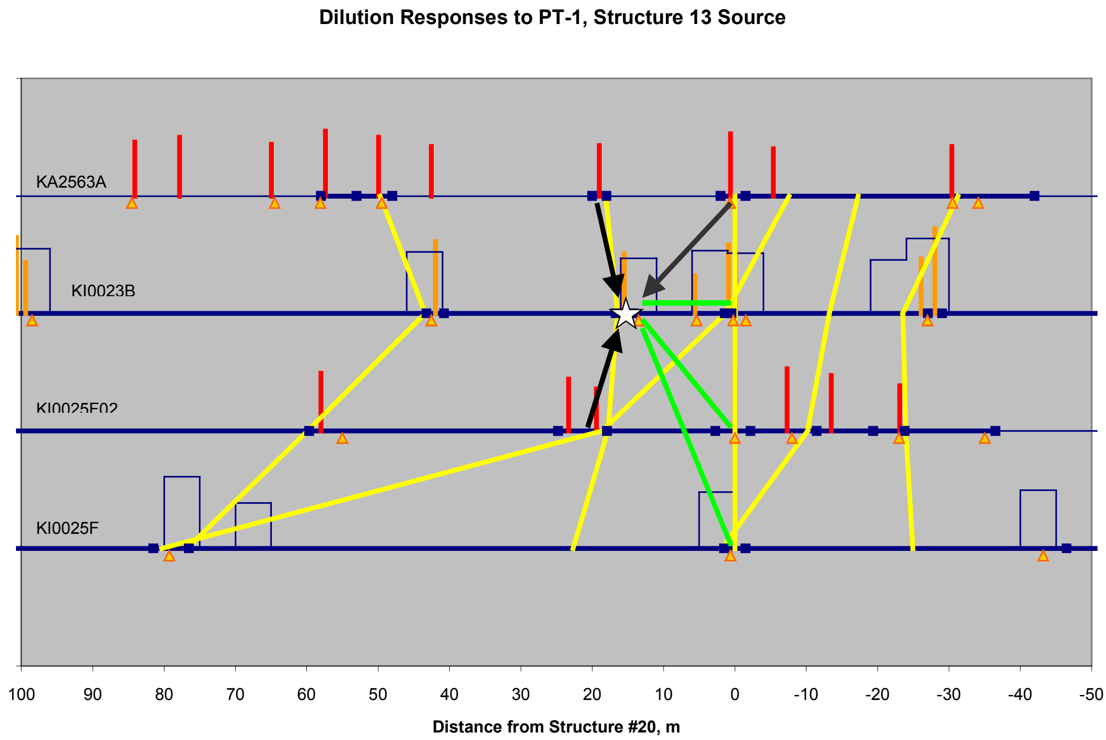


Figure 7. *Dilution results from PT-1, withdrawal from KI0023B:P4 (Structure #13). The star indicates the pumping interval. Black arrows show dilution responses. Green lines show no-response results. Boreholes are shown schematically and not in true map locations. Distances on the x-axis are measured from the intersection with Structure #20.*

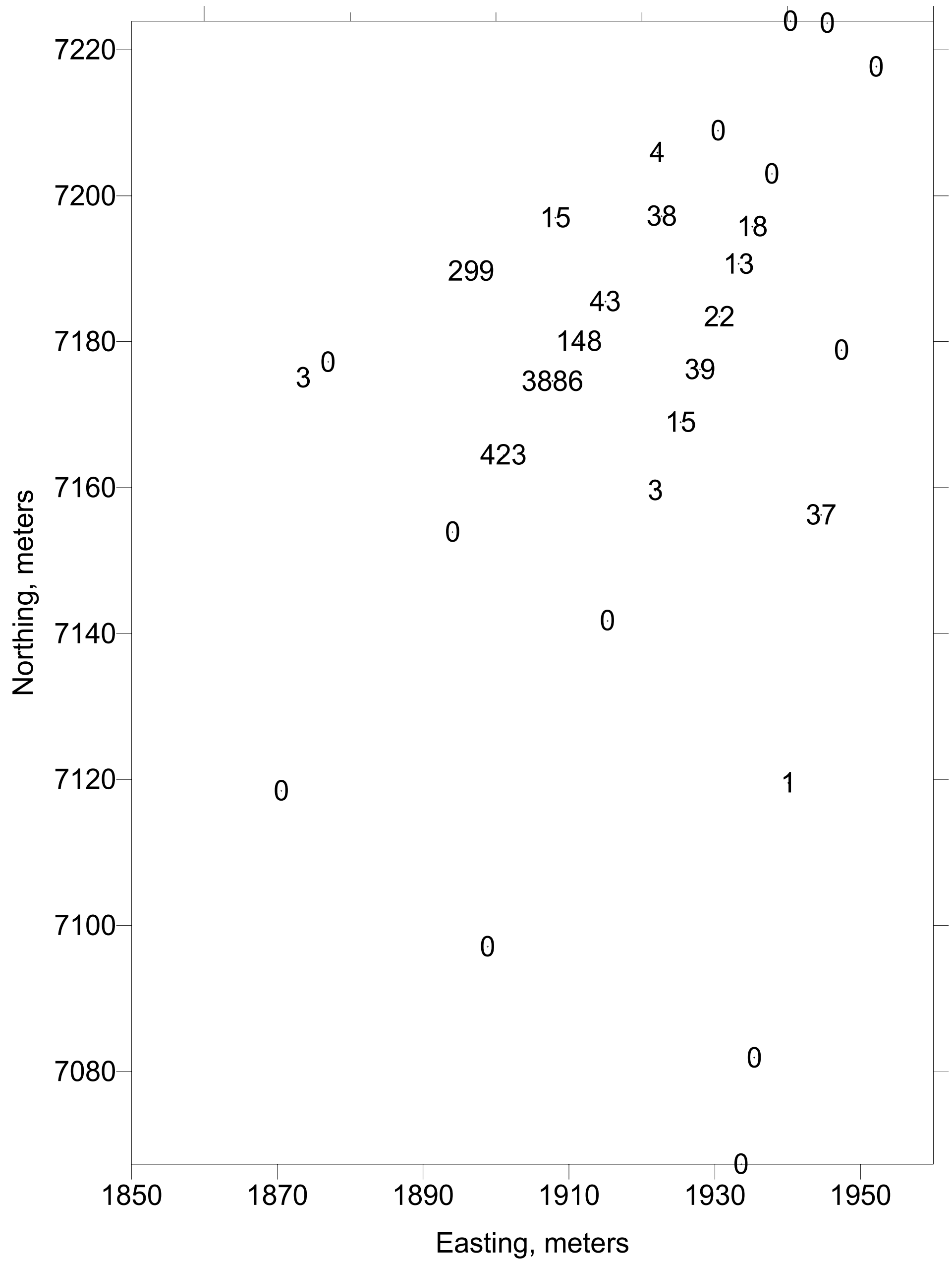


Figure 8. *Drawdown map in kPa of Pretest 1 (withdrawal from KI0023B:P4, Structure #13)*

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Withdrawal zone has a drawdown of 3886 kPa.

5.2 Structure #22

Structure #22 is one of two features that Hermanson (1999) proposed in the March'99 model that might provide connections between Structure #20 and #13. The structure was inferred mainly from a Posiva flow log anomaly at about 67 meters in KI0025F02.

One reason Structures #21 and #22 has not been proposed previously was that they appear very close to other major features in the boreholes that existed before KI0025F02. Hence it was difficult to find separate, clear pressure responses due only to Structure #21 or Structure #22. KI0025F02 provides a clear intercept of Structure #22 that has a several meter separation from Structure #20 and is visible in the pressure responses to drilling.

The drilling records reveal the presence of Structure #22 in KI0025F02 as a hydraulically conductive feature as shown in Figure 3. There is a clear pressure response in all monitored boreholes to the double drop from the intersection with Structure #22 followed shortly by the depressurization of the main trace of Structure #20.

In the pressure interference responses of the pretests, Structure #22 (KI0025F02:P6) behaves as an integral part of the Structure #20 network. Figure 9 shows the drawdowns from a short-term interference test using KI0025F02:P6 as a source. The test shows the broad responses of the Structure #20 system and its connections to Structure #13. It also shows responses in the adjacent section 7 of KI0025F02. As discussed below, this feature acts as part of the bridge from Structure #20 to Structure #6. The structure does not extend to the northeast, as there appears to be no flow anomalies along the projections of the structure to KA2563A or KI0023B.

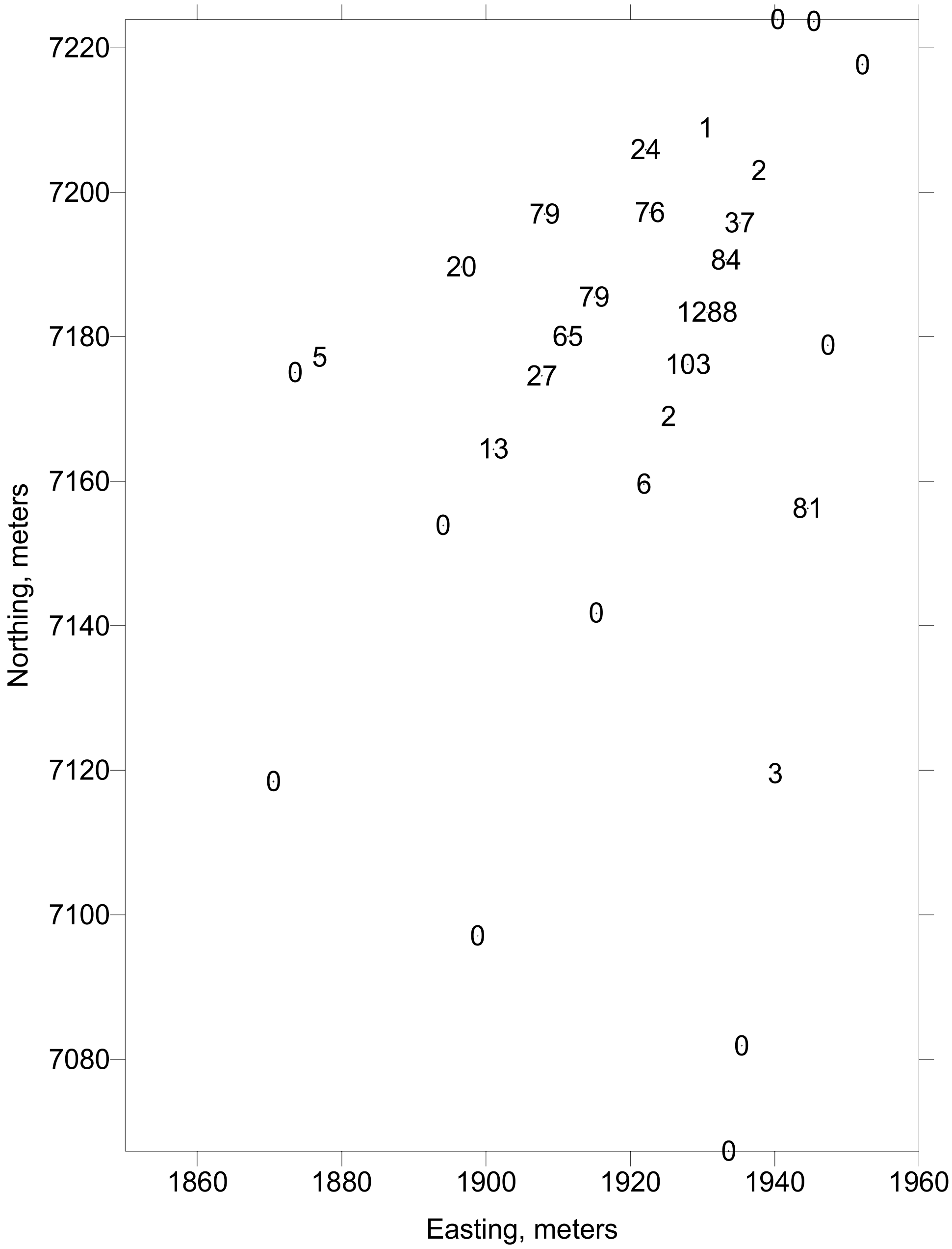

Figure 9. Drawdown responses (kPa) to short-term withdrawal from KI0025F02:P6 (Structure #22).

Withdrawal is from the zone with the 1288 kPa drawdown.

5.3 Structure #20

Structure #20 is the predominant hydraulic feature in the central part of the TRUE Block Scale volume. Section KI0025F02:P5 was used as a withdrawal zone for Pretest PT-3. The dilution results for PT-3 are shown in Figure 10, and Figure 11 shows the pressure drawdowns.

The Pretests confirm the existence of Structure #20 in its hypothesized location. Structure #20 continues to appear as the dominant hydraulic feature in the central part of the TRUE Block Scale volume. In all of the Pretests, all of the Structure #20 intervals have nearly the same drawdown. The fact that drawdowns are similar in all sections suggests that the structure has a finite extent and is recharged from connections over its surface rather than from its ends. Were the structure being recharged from its ends, there would be a gradient in head along the structure's extent and we would see variable head values at different points in the structure.

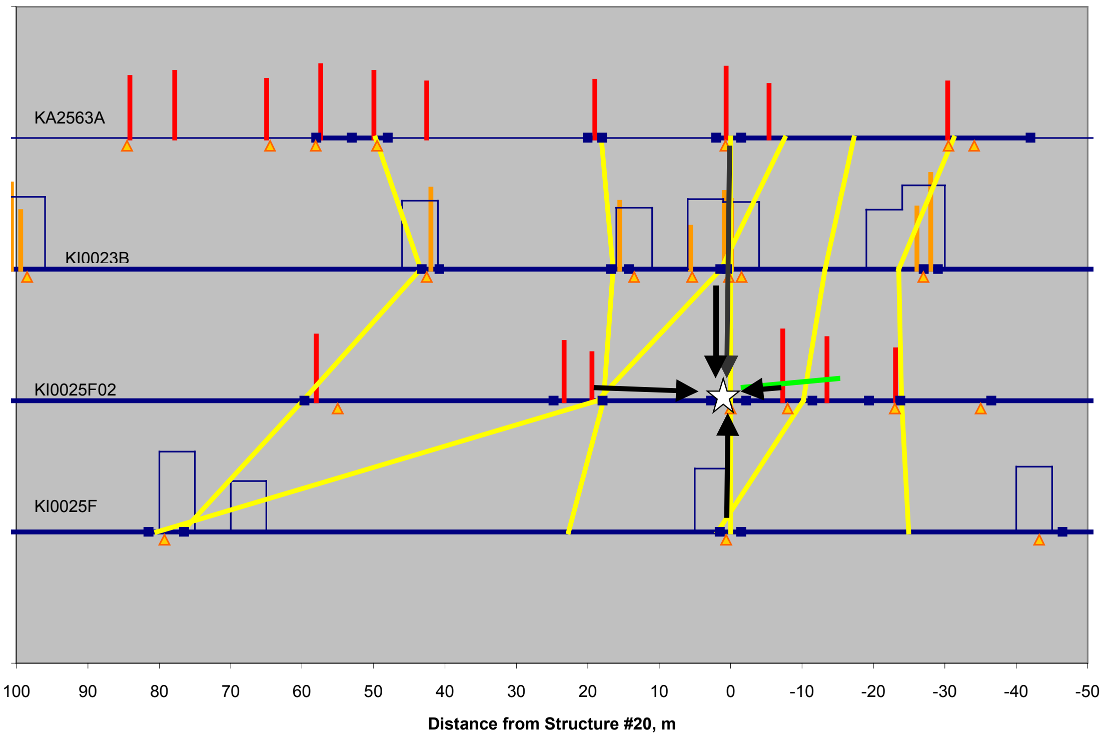

Figure 10. *Dilution test results for Pretest PT-3 (withdrawal from KI0025F02:P6, Structure #20). Dark arrows show responding intervals. Green lines show non-responding intervals.*

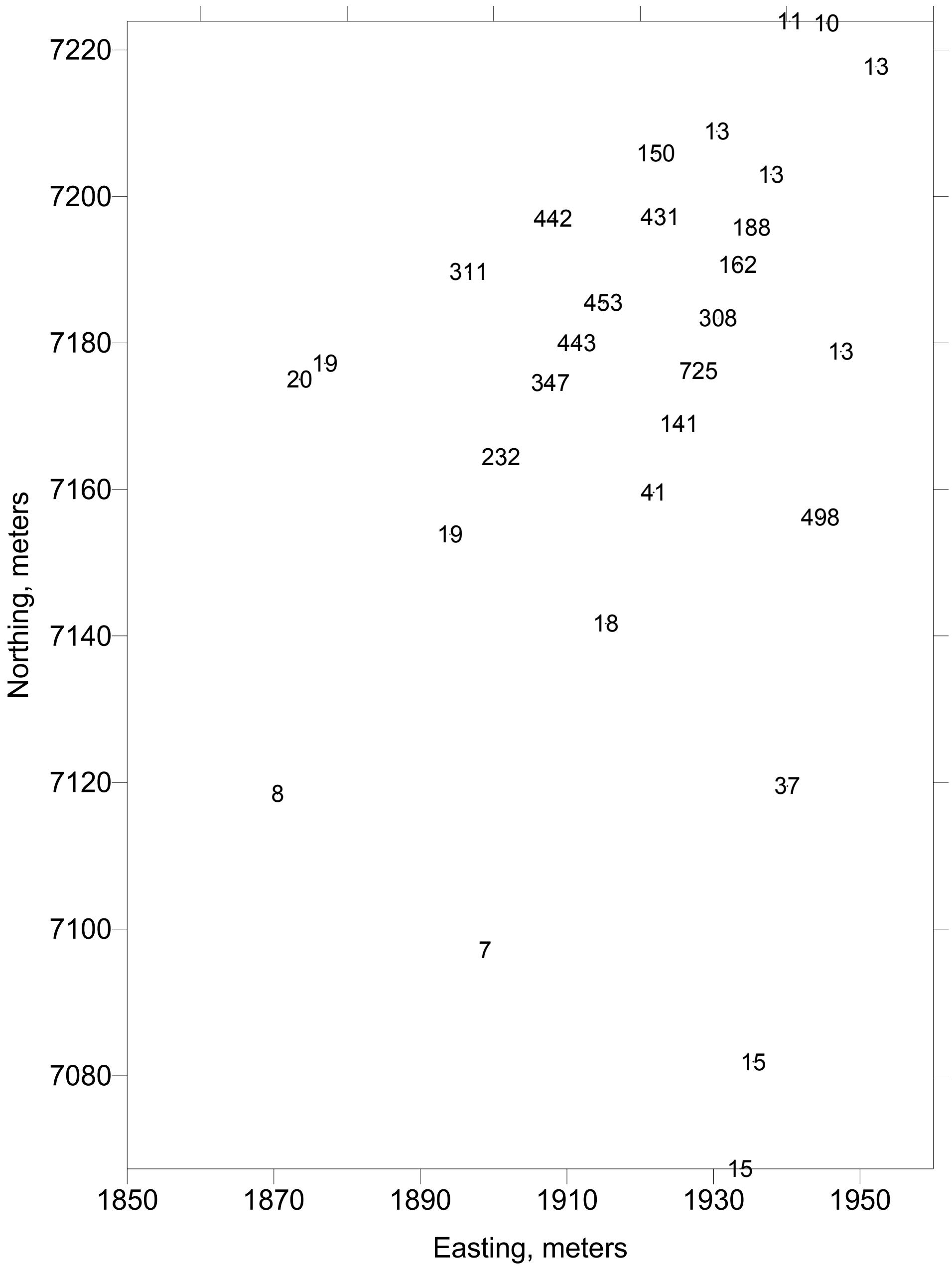

Figure 11. *Drawdown map for Pretest 3, pumping from Structure #20. Drawdowns in kPa. Pumping zone has a drawdown of 725 kPa.*

5.4 Structure #21

Hermanson (1999) suggested the existence of a conducting feature that cross cuts and connects Structures #20 and #13. This feature, Structure #21, has two proposed intersections, one in KI0023B:P6 and the other in KI0025F02:P3. This structure may have been overlooked previously, because these intersections are very close to those of other conducting features. For the KI0023B:P6 interval, the proposed Structure #21 is within 2 meters of the main trace of Structure #20. For KI0025F02:P3, the interval contains both Structure #13 and proposed Structure #21.

As mentioned above, features that crosscut Structures #20 and #13 are very important for tracer test design, hence an examination of the evidence regarding Structure #21 is a key part of this reconciliation exercise. The major new information on Structure #21 comes from two interference tests -- the third pre-test, PT-3, which used KI0023B:P6 as a withdrawal point, and a short-term interference test on KI0025F02:P3.

The hydraulic evidence for Structure #21 comes from the tracer dilution tests done during PT-2 (Figure 12), the pressure interference tests done during PT-2 (Figure 13), and a short interference test that was done using KI0025F02:P3 as a sink (Figure 14). Thus both intersections of Structure #21 with boreholes have served as sinks for interference tests.

The pressure interference data and the tracer dilution data offer somewhat contradictory evidence for Structure #21. The tracer dilution data for Pretest 2 show a clear connection between KI0023B:P6 and KI0025F02:P3 (Figure 12), and this is the strongest indicator of either a Structure #21 or some other connection between Structure #20 and Structure #13 in this area.

Of the two intersections, KI0023B:P6 is more difficult to use to infer structures because it lies so close to the Structure #20 intersection. Given this proximity, KI0023B:P6 effectively acts as part of the Structure #20 system. Hence, the main focus for demonstrating Structure #21 is the data from KI0025F02:P3.

The pressure interference tests do not indicate a strong hydraulic connection between KI0025F02:P3 and other proposed Structure #21 locations. The most striking aspect of the pressure behavior of KI0025F02:P3 is its generally low-pressure response. When discussing Structure #13 above, this low-pressure response was explained as a possible boundary effect where Structure #21 was acting as a very permeable boundary that reduced the pressure responses to pumping in Structure #13. By this logic, Structure #21 should be more transmissive than Structure #13 and pumping in Structure #21 at KI0023B:P6 should produce stronger drawdowns in KI0025F02:P3 than pumping in Structure #13, as was done in Pretest PT-1.

Unfortunately for clarifying the hydraulic structure, PT-2 produces only slightly stronger drawdowns in KI0025F02:P3 than PT-1 did (Figure 13). There are clearly connections between KI0025F02 and Structure #20, but these do not support a very direct connection along a possible Structure #21. We can also look at the drawdowns produced when KI0025F02:P3 is used as source in a short pressure interference test (Figure 14). These, too, show a relatively weak response in the intervals where one would expect to find Structure #21. In addition to the drawdown responses, the delay times (t/r^2) between pumping in the PT-2 source and pressure responses in KI0025F02:P3, are listed as “medium” in the pre-test response tables (Andersson et al., 1999).

One could look for another candidate intersection of Structure #21 in KA2563A:S5 (Figure 1). This zone contains a conductor at the right location, but sharing a piezometer interval with structures#6 and 7 may smear its pressure responses. KA2563A:S5 does have strong drawdown, but the behavior is consistent with the responses of other parts of structure 6. In general, PT-2 creates similar drawdown responses as PT-3, which pumped Structure #20. One may conclude from the similarity of the responses of these two tests that the conductor identified in KI0023B:P6 is part of the Structure #20 system.

In conclusion, the evidence for Structure #21 mainly comes from the geology and the tracer dilution tests. Tracer dilutions during PT-2 indicate a pathway along the proposed structure, however the pressure interferences do not suggest a strong hydraulic pathway.

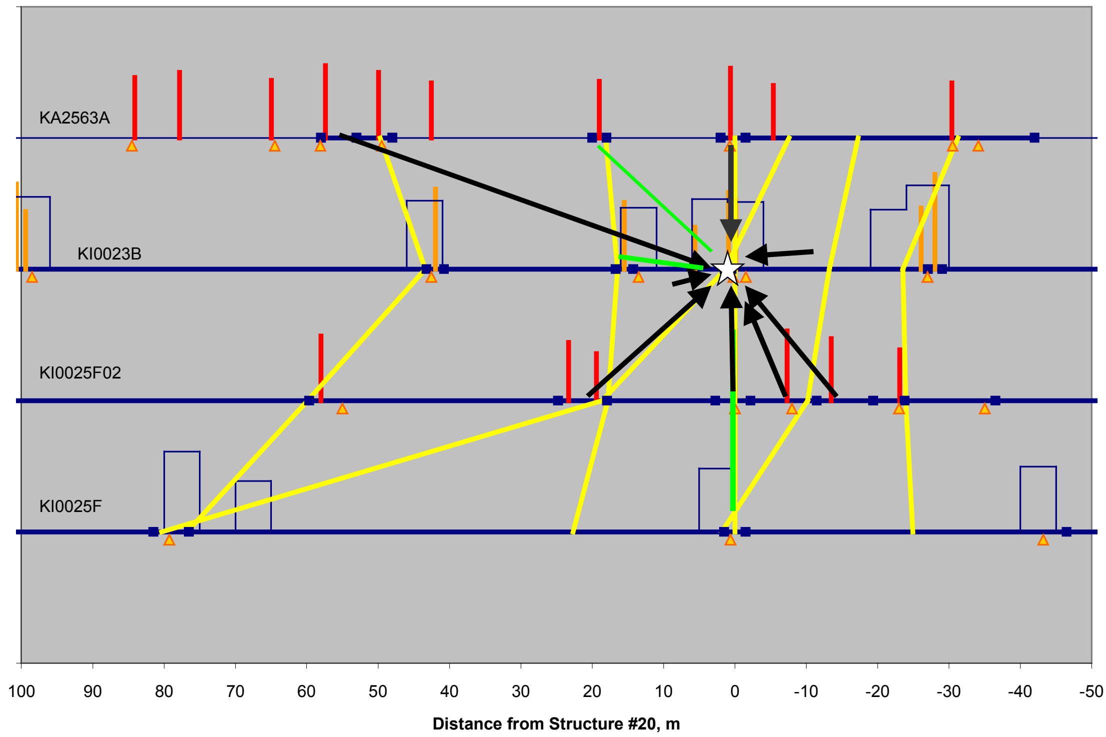

Figure 12. *Results of tracer dilution test PT-2 withdrawing from KI0023B:P6 (Structure #21)*

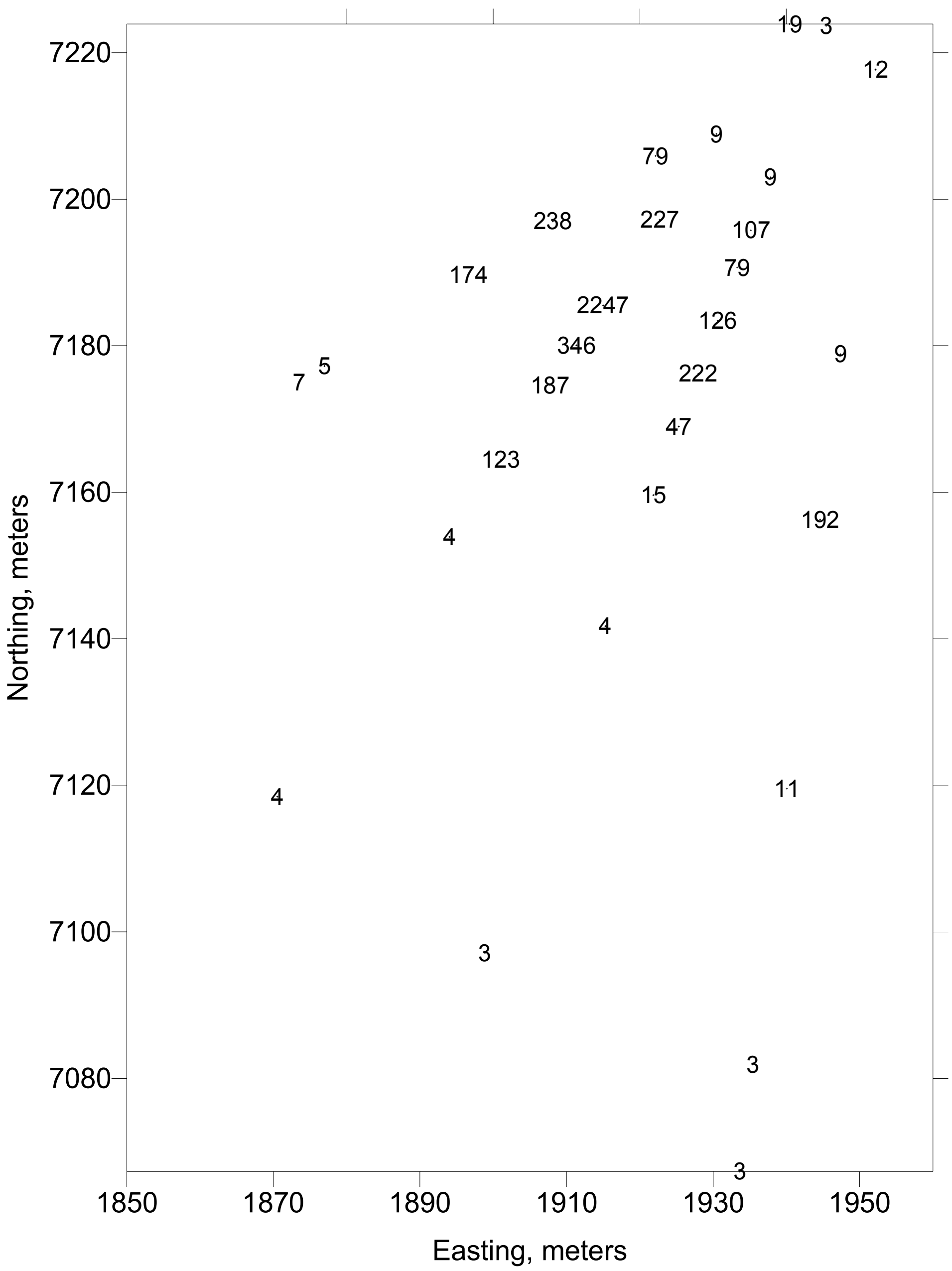

Figure 13. *Drawdown map in kPa of Pretest PT-2 (KI0023B:P6, Structure #21). KI0023B:P6 has a drawdown of 2247 kPa. KI0025F02:P3 has a drawdown of 15 kPa.*

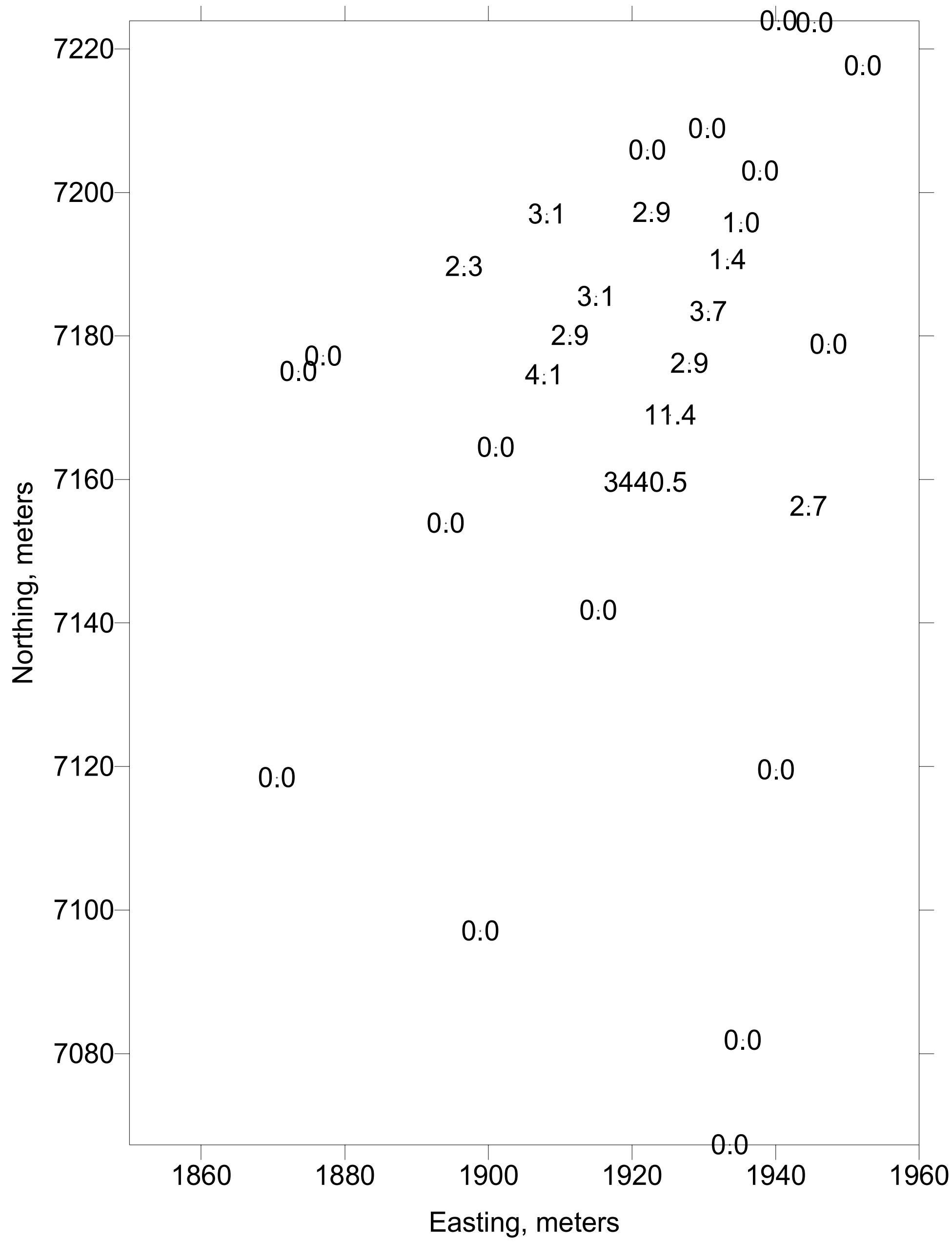

Figure 14. *Drawdown map of short-term test in KI0025F02:P3, an interval containing Structures #13 and #21. Drawdowns in kPa. Source zone has a drawdown of 3440.5 kPa.*

5.5 Additional Feature: Conducting zone in KI0023B:P5

This section describes the evidence for an unnumbered conductive feature that lies in piezometer interval KI0023B:P5 between 72.95m and 83.75m. This interval separates Structure #13 and the Structure #20-21-22 system, and conductive fractures within it may connect the numbered features. These connecting fractures are major targets for the tracer test design. KI0023B lacks the detailed Posiva flow logging of other holes, however, the 5-m flow logs of (Gentzschein, 1998) and selective build-up tests (Adams, 1998) provide a basis for providing some detail on the locations of flows.

The entire flow of KI0023B:P5 was measured as 0.42 l/m in spring 1998 (Andersson, personal communication). The drilling records for the hole indicated flow of 9 liters per minute between 72.48m and 75.38 meters. This flow after drilling was not sustained and may have indicated either a conductive feature that had a very limited volume and did not recharge after initial de-pressurization or an erroneous measurement of flow.

Gentzschein's 5-m logs used test sections of 71m-76m, 76m-81m, and 81m-86m. These zones yielded flows of 3.7, 0.0023, and 0.8 l/m respectively. The 0.42 l/m clearly does not come from the 76m to 81m interval.

Adams' tests in the depth zone of KI0023B:P5 ran in the intervals 75.1m-76.1m, 78.3m-79.3m, and 78.6m-79.6m. The shallow interval yielded very low transmissivity values between 8.8×10^{-10} m^2 and 6.1×10^{-9} m^2/s depending on the portion of the build-up curve that was used. The other two intervals were too low in transmissivity to yield data that could be analyzed. Adams obtained a flow rate of 0.051 l/m at a drawdown of 104 kPa from the 85.0-86.0 interval. Normalizing this value to atmospheric pressure gives a flow rate of about 2 l/m, which would account for Gentzschein's flow between 81m and 86m. Hence we may conclude that the flow from KI0023B:P5 is coming from between 72.48 and 75.1 meters.

Based on investigation of the borehole television data, Andersson (personal communication) proposes other candidate fractures at 73.1m (striking 107 and dipping 77) or 73.8 (striking 103 and dipping 90). These are roughly parallel to Structure #21 (striking 123 and dipping 86).

KI0023B:P5 exhibits strong pressure interference responses to all of the pre-tests and it appears to have good connection to both Structure #13 and the #20-21-22 system, although these responses in part may be artifacts of piezometer performance.

5.6 Additional Feature: Conducting zone in KI0025F02:P7

This section describes a conductive feature in region between Structure #6 and Structure #20 in piezometer section KI0025F02:P7. The Posiva flow logs for KI0025F02 (Rouhiainen and Heikkinen, 1998) indicate a flowing feature at a depth of approximately 59.2 meters having a flow rate of about 0.15 l/min.

The interval was included in build-up tests performed by Adams (1999) which tested from 58 to 62 meters obtaining a steady-state transmissivity of 1.1×10^{-8} m^2/s. Hermanson's draft structural model report (Hermanson, 1999, Figure 3-3) shows a steeply dipping fracture at this location with a strike roughly parallel to Structure #6.

This section produces pressure interference response to all of three pre-tests. These responses are similar to and generally are slightly lower than the responses of the adjacent piezometer intervals, section 6 (Structure #22) and section 8 (Structure #6). Given the short-circuiting of structures 6 and #20 in KI0023B, it can be difficult to determine whether or not the conductor in KI0025F02:P7 is associated with the Structure #20-22 system, the Structure #6 system, or both.

The pressure response data from drilling and the short term interference test that was run using this interval as a source (Figure 15) suggest that this feature is connected to both the #20-22 system and the Structure #6 system, with a preferential connection to the latter. The pressure responses when the drilling reached a depth of about 59 meters (Figure 2) show a minor, but distinct, response at a depth of about 59 meters in KI0023B:P7, which contains Structure #6. Also the short term interference test run on this interval shows strong responses in both Structure #22 and Structure #6, with a slightly greater drawdown in Structure #6 (Figure 15).

These data together suggest that the conducting feature in KI0025F02:P7 is part of the network that connects Structure #6 and the Structure #20-22 system. As such, it may be a possible target for tracer testing if a pathway involving several conductors is desired.

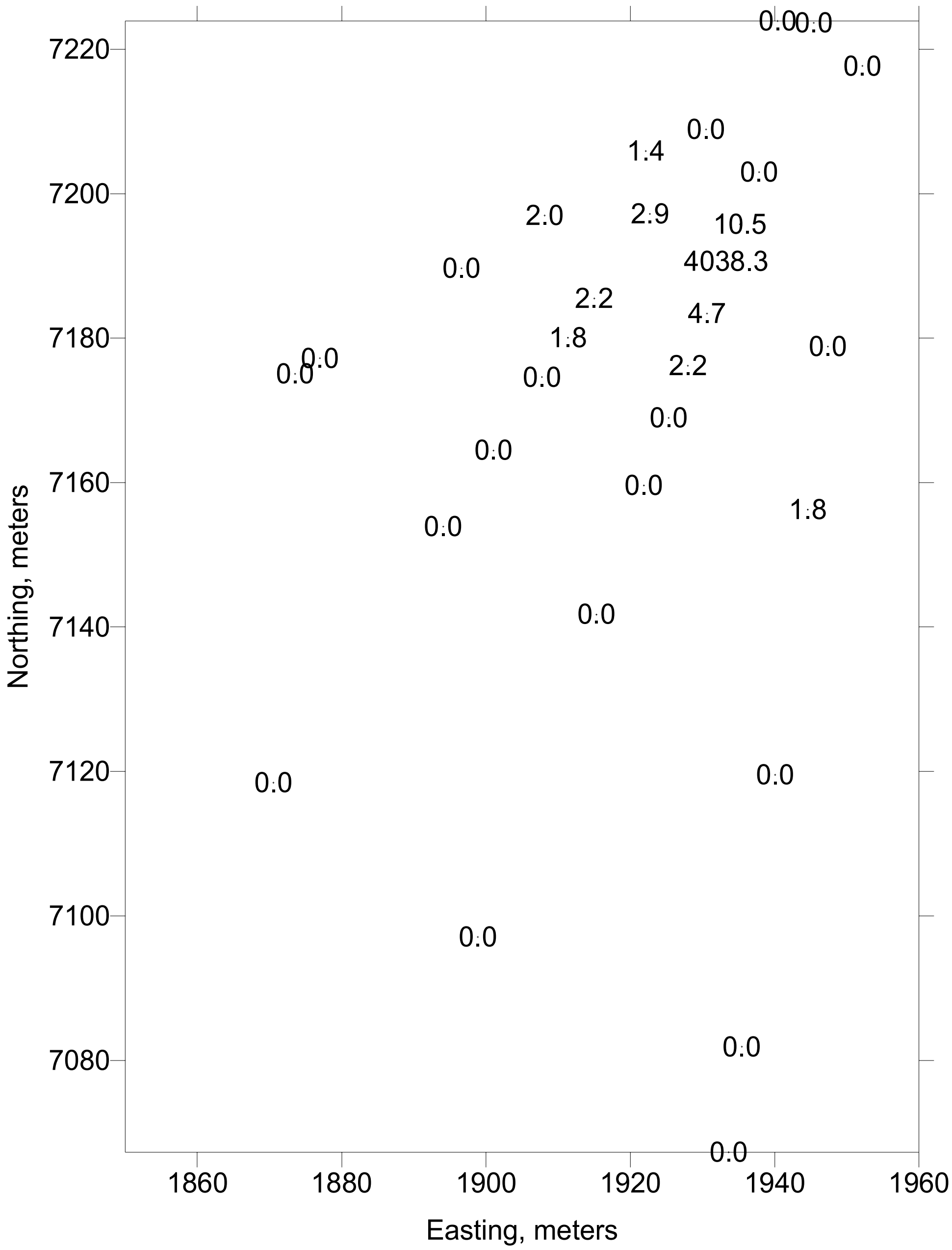

Figure 15. *Drawdown map for short-term pressure interference test on KI0025F02:P7. Drawdowns in kPa.. The source zone has a drawdown of 4083.3 kPa. Data show connections to Structure #6 zones, as well as the Structure #20-22 system.*

5.7 Additional Feature: Conducting zone in KI0023B:P3 (connection to #13)

A striking feature of the pretest results is the relatively strong responses of KI0023B:P3 (87.2-110.25). Throughout the Pre-tests, this interval also closely tracks the pressure of KI0023B:P4, which contains Structure #13. It should be noted that this interval also responds to pressure interference tests in Structure #19 (Figure 16), though not as strongly as to tests in Structure #13.

A review of the transmissivity data for KI0023B:P3 shows that it is relatively non-transmissive. KI0023B:P3 is a relatively tight zone according to the 5-m packer logs (Gentzschein, 1998). The most conductive portions the interval are from 86-91 meters (5.7×10^{-10} m^2/s) and the interval adjacent to Structure #19 between 106 and 111 meters (4.5×10^{-10} m^2/s). For the 86-91 meter interval, Adam's(1998) build-up tests give transmissivities between 1.8×10^{-10} for early time data to 3.8×10^{-9} m^2/s for late time matches. The builds up tests were unable to obtain a transmissivity for the interval between 109-5 and 110.5 at the other end of the piezometer section. As to geologic features, Hermanson (personal communication) found a fault striking 179 and dipping 82 degrees at 87.7 meters.

The pressure responses of KI0023B:P3 to the Pretests may reflect leakage, deformation, or other effects of the borehole equipment. This particular piezometer interval has collapsed and the flow and pressure monitoring lines are exposed to the water in the test section raising the possibility that tubing deformation effects might account for some of the fast responses. Given the low transmissivity of this interval, an artifact of the equipment is likely.

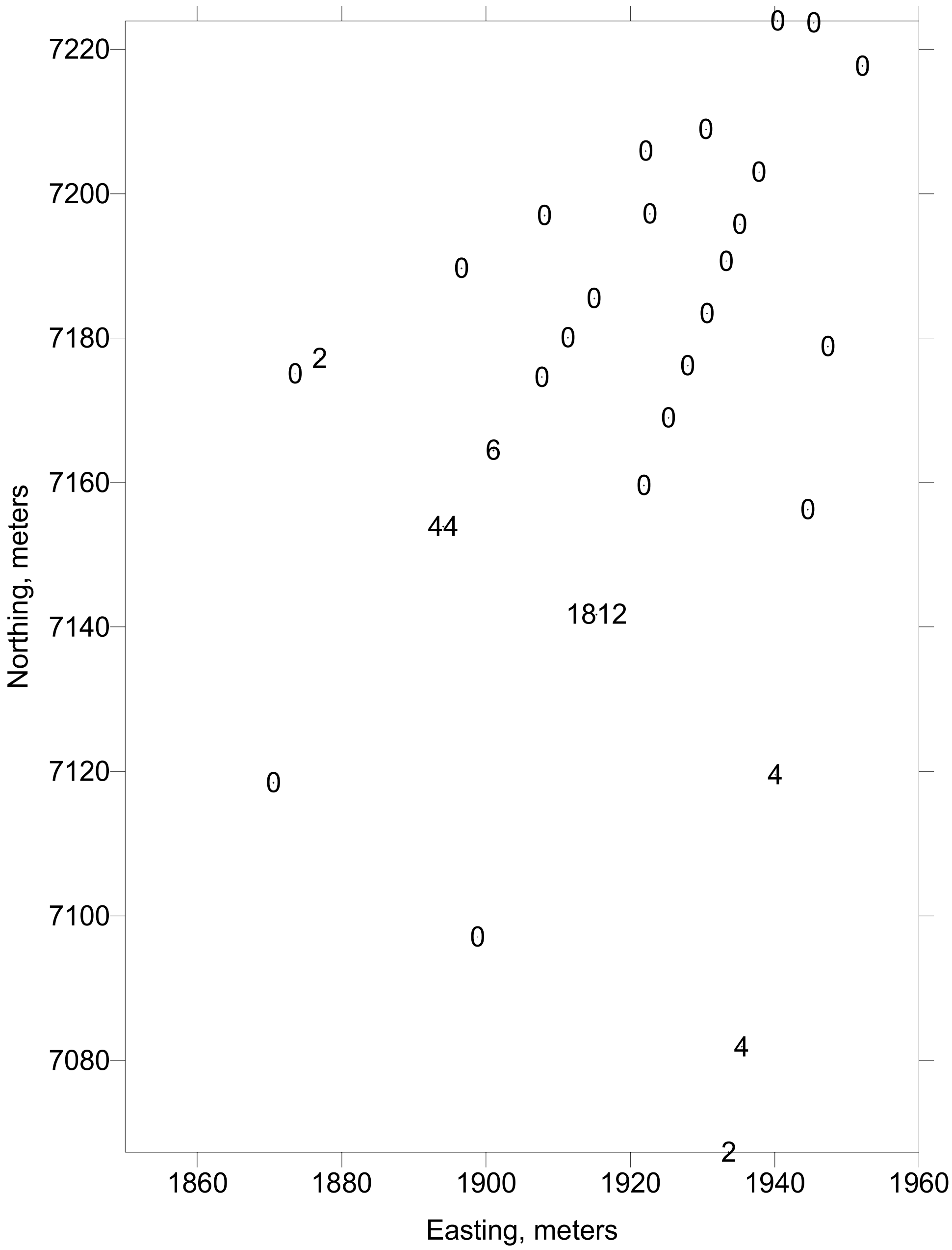

Figure 16. *Drawdown map of short-term pressure interference test in KI0025F02:P2 (structure 19) Drawdowns in kPa, and source zone has a drawdown of 1812 kPa. Note relatively strong drawdowns in KI0023B:P3.*

5.8 AdditionalFeature(oranomalousconnection): KA2563A:S1

The piezometer interval, KA2563:S1, clearly shows a better connection than other parts of Structure #19 to Structure #13 and other parts of the Structure #20 flow system (PT-1, Figure 11). Indeed, its drawdown response to all of the pretests exceeded that of its neighbor zone in Structure #19, KA2563:S2. In addition to the pressure responses, this KA2563:P1 also displayed an increase in flow rate in dilution tests conducted during PT-2 (Figure 12).

In a prior installation of the KA2365 piezometer, there was an even stronger connection from zone 1 to the Structure #20 area that turned out to be an artifact of the equipment rather than a real hydraulic connection. It is not clear whether or not this is also the case for the present piezometer equipment, but some checking might be appropriate.

5.9 Structure 19

Structure 19 is a distinct northwest trending conductor that intersects all boreholes except for KA2511A. Structure 19 appears clearly in the pressure monitoring records of the holes as they were drilled, and it is prominent in later interference tests, where 19 was a source.

Structure 19 will be addressed in later Pretests. We do have results from the short term interference tests that were run on sections of KI0025F02 after that hole was drilled (Figure 16). These results show that Structure #19 is a relatively isolated feature with little connection to the rest of the True Block Scale volume.

In reviewing Figure 16 it should be noted that this test was performed before the piezometer in KA2563A was modified to monitor the interval from 236 to 241 meters, which contains the main trace of Structure #19. At the time this test was run, that trace lay in an unmonitored section of the hole.

The second point about Structure #19 is its connection to the central portion of the True Block Scale volume, specifically to structures #13 and 20. In all of the pretests, all of the section 19 intervals respond similarly, except for section KA2563A:S1 that has a somewhat larger drawdown than the other intervals. Furthermore, dilution tests that were run using this interval during pretest, PT-2, showed a flow rate change due the pumping of Structure #21. Previous installations of the KA2563A piezometer had connections between deep piezometer intervals and other zones around Structure #20 that were artifacts of the equipment, and not part of the natural system. While the preferential connection of the current KA2563A:S1 interval is very small compared with the previous artifact, the data and installation should be reviewed to be sure there is not trace of the previous equipment artifact.

5.10 Structure 10

The deepest recognized structure in the TRUE Block Scale volume, Structure #10, appears at the ends of KI0023B, KI0025F02, and KA2511A. There are deeper conducting features, however these do not produce cross-hole hydraulic responses. Except for structure 5, this is the only structure that intersects KA2511A and the other boreholes of the TRUE Block Scale volume. Part of the reason for KA2511A's lack of response to the other holes is its position above the main borehole array. A short-term interference test was performed using KI0025F02:P1 as a source interval, and this test provides a drawdown map that delineates this deep structure (Figure 17).

Hermanson (1998) proposed a location for Structure #10 in the September 1998 structural model. This location was not modified in the March 1999 model most likely because this structure lies outside the main region of interest for testing in the TRUE Block Scale volume. The structural model places Structure #10 at 157.2 meters in KI0025F03, however, cross-hole responses appeared when KI0025F02 was between 172.4 and 175.4 meters. Flow logging and hydraulic testing indicate the depth of this conductor is between 172.7 and 173.7 meters.

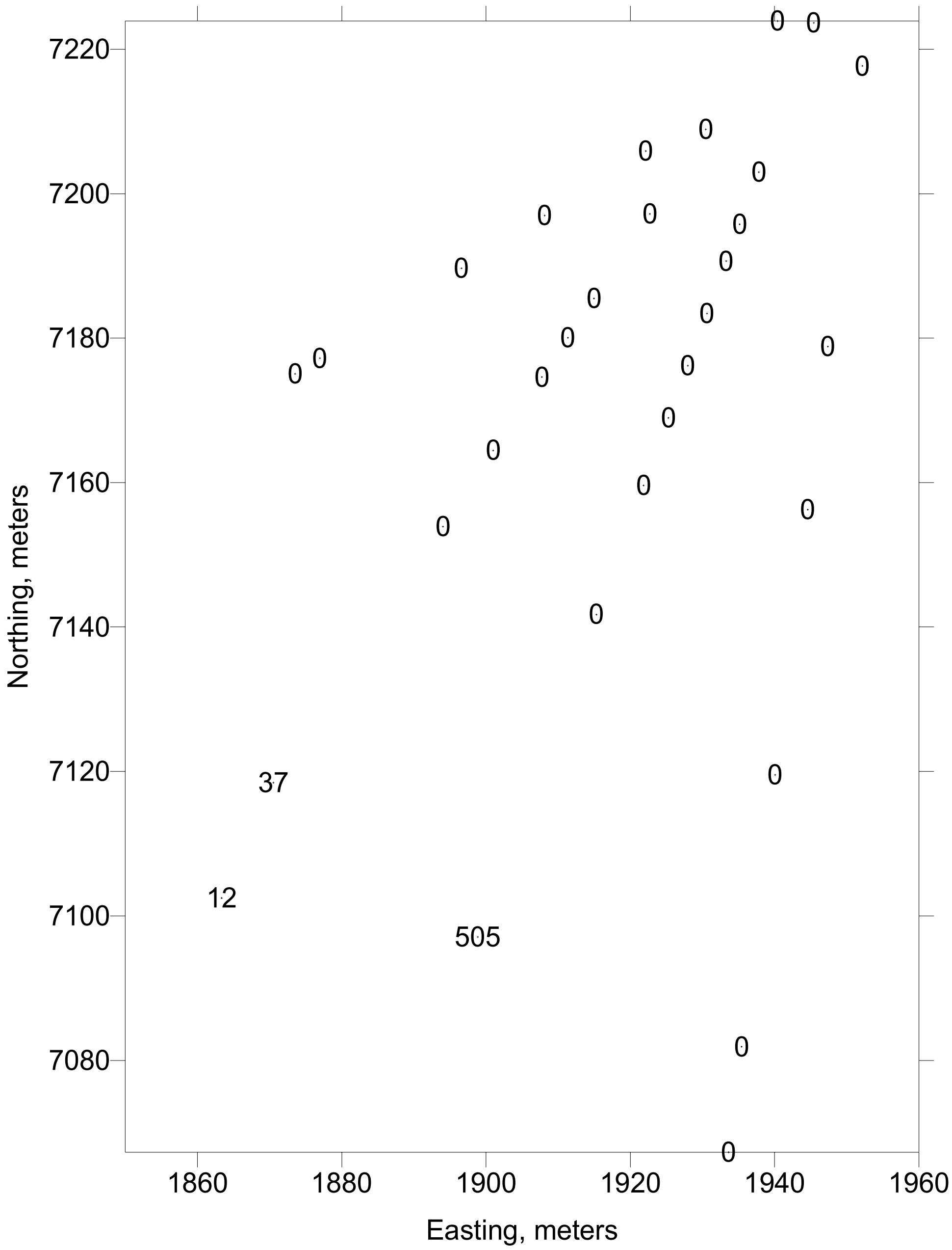

Figure 17. *Drawdowns due to short-term pumping in KI0025F02:P1 (Structure #10) shown in kPa. Withdrawal zone has a 505-m drawdown.*

6. Summary of Hydraulic Model

6.1 Locations of Hydraulic Structural Features

An analysis of the hydraulic data provides a clear verification of the major elements of the March 1999 structural model. This section summarizes the evidence for structures as hydraulic features. Figure 18 compares the reconciled features to the hydraulic data. Figure 19 shows the features in map view with terminations based on presence and absence of hydraulic responses in specific locations.

Structure #20 is at the heart of a conductive system in the core of the True Block Scale volume. It is continuous and has clear pressure and dilution signatures.

Structure #13 is distinct from but clearly connected to the Structure #20 system. There are strong Structure #13 connections between KI0023B and KA2563A. As to KI0025F02, dilution tests that were run during PT-1 suggest a good connection along Structure #13 between these holes. The pressure responses are less clear in confirming this Structure #13 connection. Pumping in Structure #13 produces relatively low drawdown responses in KI0025F02, but these may be due to constant-pressure boundary effects caused by Structure #21 being in the same observation interval as Structure #13. Structure #13 may disappear to the southeast between KI0025F02 and KI0025F.

Structure #22 clearly exists in KI0025F02, but does not appear to extend into KI0023B or KA2563A. This structure is hydraulically part of the Structure #20 system, and may constitute a splay of Structure #20. Pressure responses suggest that splays of Structure #22 or other conductors may provide hydraulic connections to Structure #6.

Structure #21 is a potentially important connection between Structure #20 and Structure #13. The dilution measurements of PT-2 and PT-3 are consistent with the existence of this connection. The low drawdowns on KI0025F02:P3 to pumping in inferred the location of Structure #21 in KI0023B makes this interpretation less clear. In short, Structure #21 is still hydraulically ambiguous.

Despite the ambiguity of Structure #21, there are clearly features that must connect structures #13 and 20. One such feature may appear in at 72 meters in KI0023B:P5. This feature currently has no number, but it responds strongly to disturbances in both Structure #13 and Structure #20. Another potential connection between #13 and 20 appears in section KI0023B:P3, however the pressure responses that suggest these connections may be artifacts of the piezometer equipment. In summary, the existence of connections between structures #13 and 20 is very clear, but fractures that provide those connections continue to be elusive.

There are at least two possible short circuits in the piezometer array. The term “short-circuit” is used to describe when two different conductors at different pressure values lie within the same piezometer interval. The result of the short circuit is a flow within the piezometer zone along the borehole. In some cases the lower pressure conductor will act as a pumping source that can interfere with tracer tests if it is not accounted for in some manner.

The most serious short-circuit is in section KI0023B:P7, which appears to contain both Structures 20 and Structure #6. This short circuit results in a very strong flow within the piezometer interval from the higher-head of Structure #20 to the lower head of Structure #6, and this flow has been measured in Geosigma’s dilution tests during pretest program. The existence of short circuits along boreholes is undesirable for tracer test design.

Another possible short circuit may lie in KA2563A:S5. As shown in Figure 18 this interval contains two conducting zones one at 157.6 meters, that is likely part of Structure #6 and the other at 182.6 meters that may be part of the Structure #20 network. It is not possible to tell from the testing whether not these two conductors are part of the same structure or network or if they are short-circuiting networks, but this would be a good place for running a dilution test to check.

The locations of hydraulically significant structures are given in Tables 1 and 2. Table 1 was developed as follows; the hydraulic extensions of the numbered structures were inferred from the pressure interference data during drilling and hydraulic testing as discussed above. The orientations of the boreholes favor interpretations in a roughly horizontal plane centered on the TRUE block scale volume, which is approximately the area where boreholes KI0023B and KI0025F02 cross Structure #20, or about 7175 (Northing), 1900 (Easting), and –477 masl (Elevation) in Äspö coordinates. There is little information on the vertical extents of the structures other than the absence of responses in KA2511A, which did not record to pressure disturbances in any structures with a few exceptions. These exceptions were Structures #7 and #5 which were intersected near the borehole collars and Structure #10 which connects boreholes KI0023B, KI0025F02 and KA2511A deep in the boreholes off the western edge of block. The coordinates and orientations for Structures #7 and #10 are added to the lists because they may be considered as hydraulic boundaries for the simulations.

The orientation information comes from Hermanson's structural models (1998 and 1999). Except for Structure #7, Table 1 extends the structures vertically 50 meters above and below Z= -477 masl. This extension avoids KA2511A for all structures except Structure #10, while including some of the intersections such as Structure #20 and Structure #13 and Structure #13 and #19. The corners of the structures use the plan view traces in the Z=-477 plane and extrapolates the ends of the structures in the directions of the structures' dips vectors.

Several important features relating to structure extent should be noted:

- The data in Table 1 extends Structure #13 across KI0025F02 and KI0025F. This extension is based on the dilution and tracer tests responses to the pre-tests. If we consider the pressure interference responses from the pre-tests and other short-term tests in KI0025F02, we may conclude alternately that the most conductive portion of Structure #13 connects KA2563 and KI0023B and is less conductive across KI0025F02 and KI0025F.
- Structure #6 does not have clear pressure responses in KI0025F and terminates between KI0025F02 and KI0025F.
- Structures #21 and #22 do not have clear extensions to KA2563A, nor does Structure #22 appear to have a hydraulic signature in KI0023B.
- Structure #9 does not appear in the model based on non-responses during the flow logging and other related testing.

Table 1 Coordinates of Structures (Reconciled hydraulic and structural model of the True Block Scale volume)

Structure	Corner	1	2	3	4
#6	Easting	1911	1907	1941	1945
	Northing	7231	7229	7184	7186
	Elevation	-427	-527	-527	-427
#7	Easting	1826	1820	2048	2054
	Northing	7262	7245	7155	7172
	Elevation	-350	-527	-527	-350
#10	Easting	1800	1807	1931	1924
	Northing	7089	7121	7109	7077
	Elevation	-427	-527	-527	-427
#13	Easting	1877	1894	1953	1936
	Northing	7193	7207	7137	7123
	Elevation	-427	-527	-527	-427
#19	Easting	1872	1860	1955	1967
	Northing	7204	7196	7046	7054
	Elevation	-427	-527	-527	-427
#20	Easting	1874	1881	1981	1975
	Northing	7227	7233	7123	7117
	Elevation	-427	-527	-527	-427
#21	Easting	1906	1924	1933	1915
	Northing	7194	7196	7131	7129
	Elevation	-427	-527	-527	-427
#22	Easting	1917	1935	1965	1947
	Northing	7191	7199	7134	7126
	Elevation	-427	-527	-527	-427

Table 2 Equations of Structure Planes (Reconciled hydraulic and structural model of the True Block Scale volume)

Equation of the Planes in the form Ax+By+Cz+D=0						
Structure	A	B	C	D	Strike	Dip
#6	0.7946	0.6053	-0.0471	-5915.65	142.7	87.3
#7	0.3659	0.9255	-0.0976	-7423.23	111.6	84.4
#10	0.0916	0.9458	0.3116	-6736.41	276.0	72.0
#13	-0.7477	-0.6283	-0.2149	5831.18	320.0	77.6
#19	0.8351	0.5320	-0.1395	-5455.44	147.5	82.0
#20	-0.7349	-0.6723	-0.0891	6197.84	317.6	84.9
#21	-0.9752	-0.1371	-0.1736	2770.80	352.0	80.0
#22	-0.8914	-0.4062	-0.2011	4543.85	335.5	78.4

6.2 Transmissivity Values for Hydraulic Structures

Transmissivity values for the structures in the TRUE Block Scale volume come from several sources including pressure buildup tests, flow tests, and flow logs. We separate the transmissivity analyses into two types – steady flow and transient flow calculations. Flow logs generally provide only steady flow data. Flow and pump tests may be interpreted using either steady or transient methods provided transient data are available. Buildup tests area always interpreted using transient methods. There are several steady flow equations for interpreting tranmissivity values, but mostly they all use the specific capacity (flow divided by pressure change expressed as a hydraulic head) times a constant that reflect assumptions about the flow geometry. Steady flow methods do not provide information on flow geometry and they can be strongly influenced by regions local to the borehole, particularly regions of lower transmissivity than the feature's average. Transient interpretations should provide transmissivity values that reflect a larger portion of the feature's area, and the area of influence is a function of the duration of the test.

Because transient and steady interpretations are not directly comparable, we report the transmissivity data in separate tables. Table 3 provides transient data by structure and borehole and Table 4 provides steady flow interpretations.

In a few cases the transmissivity value is given for two structures together, as for Structure #22 and Structure #20 in KI0025F. We have lumped values where two structures appear within one meter of another, such that a test is likely to be affecting both features.

There are three main sources of transient data. These are build-up test analyses that were run in KI0025F (Gentzschein and Morosini, 1998), KI0023B (Adams, 1998), and KI0025F02 (Adams, Andersson, and Meier, 1999).

Table 3 also includes the results of pressure interference tests that were reported by Andersson, Ludvigsson, and Wass (1998). These data were reported as interference values at various monitoring points. Table 3 presents the average of these values in the position of the table corresponding to the source structure and borehole. The table gives the arithmetic average, however other averaging calculations may readily be made by consulting the data in Andersson et al (1998). In addition some individual estimates from the transient evaluation of PT-1 (#13 in KI0023B) and PT-3 (#20 in KI0025F02) are reported (Andersson, et al. (1999).

Table 3 also presents well test analyses using Golder Associates Flowdim code. For purposes of comparison, the values presented here are for the best matches using an assumed dimension of 2. The Flowdim results generally agree well with other transient data interpretations. Where differences appear, they mainly reflect the accounting of skin effects, which appear strongly in some tests.

Adams (1998) and Adams et al (1999) report several values for each of their build-up tests. For constructing Table 3, we selected the value we thought best reflected the large-scale properties of the structure. Accordingly we used the late-time weighted values from the build-up tests. Flow-period, transient results are used in Table 3 only where the build-up results are questionable, such as where the period of infinite acting behavior has insufficient duration.

Gentzschein and Morosini (1998) report transmissivity values using steady-flow methods, the semi-log straight line method (Jacobs assumption), and an approach that matches the entire pressure history of all phases of the test using the Saphir code. Gentzschein and Morosini do not recommend using the steady flow values for reasons of skin effects, hence Table 3 only reports the transient analysis values. In addition, the value shown for structure 19 is the sum of three, 1 m tests between 165.3 and 168.3 meters.

Most of the transmissivity analyses reflect tests having relatively short durations, generally about 30-minutes of flow. This duration raises some question about what magnitude of length scales these values represent. The radius of investigation of a well test is function of the structure's hydraulic diffusivity, which is the ratio of transmissivity to storativity. Diffusivity is the fundamental parameter obtained from interference tests. According to Streltsova (1988) the radius of investigation, R_I, is related to diffusivity, η, by $R_i = A\sqrt{\eta t}$, where A depends on the definition of what magnitude of drawdown constitutes no response. For the range of "*A*" values in Streltsova (1988, Table 2.8), and using typical diffusivity values from Andersson et al (1998, Table 4.3b) of about 10, a 30-minute test should influence a region to a distance between 180 and 600 meters. For an order of magnitude lower diffusivity, this range is about 50 to 200 meters. One may conclude that the transient test results are affecting significant volumes of the structures being tested.

Table 4 presents the steady flow values. As mentioned above, steady flow methods use the specific capacity multiplied by a constant that reflects geometric assumptions. For the packer logs, we have reported the calculated values as presented in Gentzschein (1997, 1998). Transmissivities calculated from the Posiva logs use an assumed head difference of 410 meters. As the Posiva meter has an upper flow limit, transmissivities where that limit was exceeded are given as lower bounds.

Table 3. Transmissivity data for structures in TRUE Block Scale volume. All data are in units of m^2/s.

Structure	KI0025F			KA2563A	KI0023B		KI0025F02		
	Flow and Buildup (Saphir)	Buildup (Jacobs)	Pump Test	Pump Test	Buildup	Pump Test	Buildup	Pump test	Flowdim
7	9.0E-07	1.3E-05	3.7E-5	2.1E-5	1.8E-05	4.0E-05	1.7E-06	-	1.8E-05
6	X	x	x	-	4.0E-07	-	1.5E-08	-	1.0E-07
Add #	X	x	x	x	x	x	5.3E-09	-	6.7E-09
22	1.8E-07	5.1E-07	8.5E-07	x	x	x	2.6E-07	-	3.7E-07
20				8.7E-07	9.6E-07	9.6E-07	6.5E-07	6.9E-7	5.9E-07
21	X	x	x	x	8.1E-07		9.6E-09	-	2.8E-09
13	X	x	x	4.5E-8	5.8E-08	3.2E-7	1.5E-09	-	1.7E-07
19	1.1E-05	2.9E-05	-	-	3.9E-06	-	1.7E-06	-	1.8E-07
10	X	x	x	x	4.5E-06	-	5.3E-8	-	1.2E-07

An “x’ indicates that a structure is not present; a “-“ indicates that the interval was not tested by this method in this hole.

Data sources:

KI0025F -- Buildup: Gentzschein and Morosini (1998)
KA2563A – Pump Test: Andersson et al. (1998)
KI0023B – Flow Log: Buildup: Adams (1998); Pump Test: Andersson et al. (1998), Andersson et al. (1999)
KI0025F02 – Buildup: Adams, et al. (1999), Flowdim (Doe and Fox, 1999), Andersson et al. (1999)

Table 4. Steady flow transmissivity data for structures in the TRUE Block Scale Volume. All data are in units of m^2/s.

Structure	KI00125F		KA2563A	KI0023B		KI0025F02	
	Packer Log	Flow Test	Posiva Log	Packer Log	Flow Test	Posiva Log	Flow Test
7	5.8E-08	4.10E-07	-	-	1.6E-05	>1.6E-07	1.8E-06
6	X	x	2.2E-08	1.5E-06	3.3E-08	1.1E-08	1.5E-08
Add #	X	x	x	x	X	5.4E-09	1.1E-08
22	3.6E-08	1.60E-08	x	x	X	>1.0E-07	3.3E-07
20			>1.9E-07	7.5E-08	1.4E-07	>1.2E-07	1.1E-06
21	x	x	6.8E-09	1.3E-07	6.9E-07	2.8E-08	5.0E-08
13	x	x	2.7E-08	2.8E-08	9.8E-08	3.9E-09	4.6E-09
19	7.3E-07	1.40E-06	9.4E-08	9.9E-08	1.2E-06	>1.1E-7	1.1E-07
10	x	x	x	1.9E-07	2.7E-06	3.3E-08	5.3E-08

An “x’ indicates that a structure is not present; a “-“ indicates that the interval was not tested by this method in this hole.

Data sources:
KI0025F -- Packer log: Gentzschein, 1997; Flow Test: Gentzschein and Morosini (1998)
KA2563A – Posiva log: Rouhiainen and Heikkinen (1999a)
KI0023B – Packer log: Gentzschein, 1998; Flow Test: Adams (1998)
KI0025F02 – Posiva log: Rouhiainen and Heikkinen (1998); Flow test: Adams, et al. (1999)

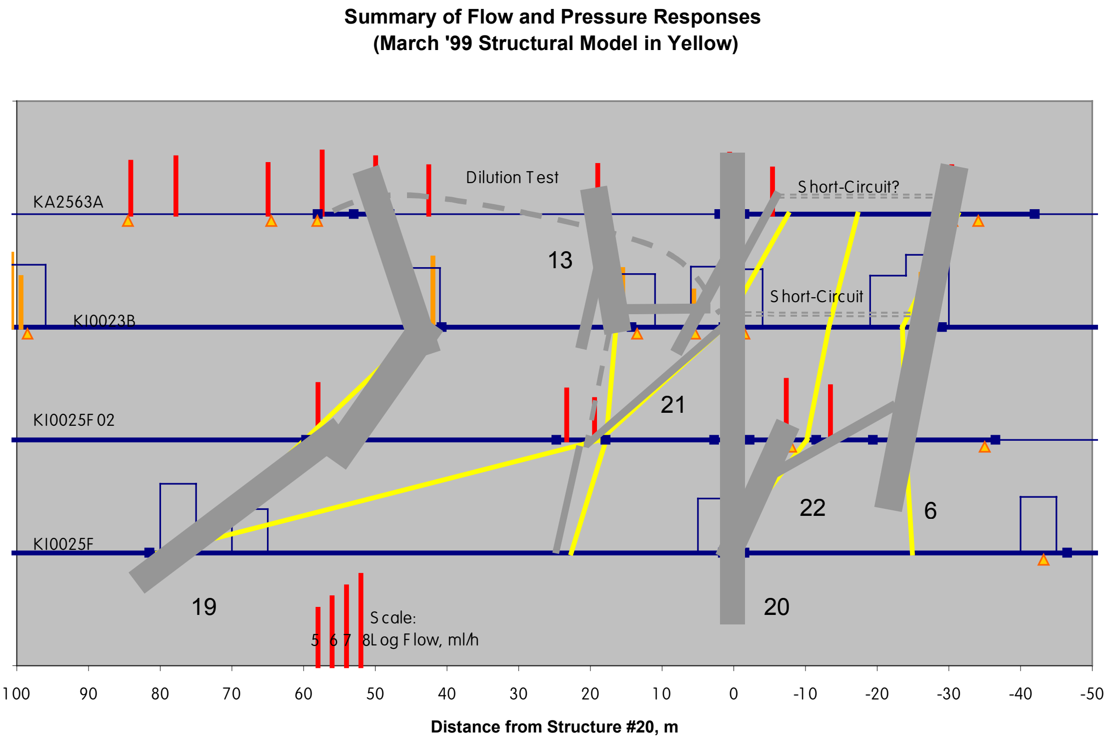

Figure 18. *Reconciled hydraulic and structural model of the True Block Scale volume. Gray shaded lines show hydraulic structures. Yellow lines indicate structures in March'99 Structural Model. See Figure 6 for explanation of hydraulic data.*

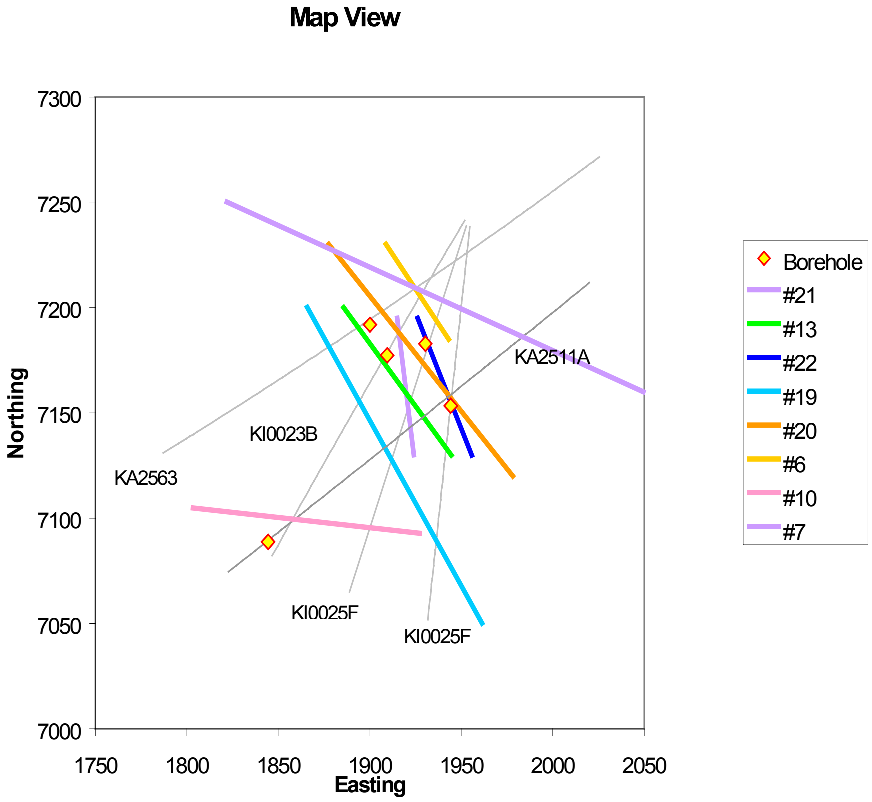

Figure 19. *Map view of structures at Äspö elevation –477 masl showing extents of hydraulic structural features (Reconciled hydraulic and structural model of the True Block Scale volume).*

7. Conclusions and Recommendations

A major goal of the TRUE Block Scale program is the testing of tracer behavior in networks of conducting features. The relevant features of networks include intersections and other heterogeneous effects that are introduced by having multiple conductors along a pathway. The structural and hydraulic model is the result of characterization work to define these conductors.

The development of the structural model and the definition of conductive pathways within the network of structures have been major accomplishments of the program. KI0025F02 and the tracer Pre-test program have confirmed the major elements of the structural model. The significant uncertainties that remain include the definition of the features the connect Structures #13 and #20, the major conducting structures in the central area of the TRUE Block Scale volume. The Pretest work largely confirms Structure #22, however Structure #21 remains somewhat uncertain. The Pre-test studies confirmed connections between Structure #6 and Structure #20 which would be an appealing alternative to the Structure #13-#20 area, except for the grouting activities in Structure #6 that reduce its value as a tracer test target.

One difficulty in defining Structure #21 is that it appears to close to other structures in the holes it intersects. One possible goal of a new borehole might be to target a location where Structure #21 is more clearly separated from other structures. Other goals for a new borehole may include optimization of spacings for tracer-test pathways or optimizing locations relative to Structure intersections.

Consideration should be given to some changes in piezometer design if short-circuits are deemed to compromise the effectiveness of tracer test. Short circuits appear when monitoring intervals include more than one structure. Possible short circuits may occur in KI0023B:P6 and KA2563A:S5.

8. Acknowledgements

Peter Andersson was an active participant in developing this effort, and the author has incorporated extensively his comments. Jan Hermanson was also strongly influential in this effort, at least until his unfortunate encounter with the animal kingdom. Anders Winberg's comments and editing are gratefully acknowledged. The author accepts all responsibility for the interpretations and any mistakes in compiling and assessing the data.

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