MARINO ENGINEERING ASSOCIATES, INC.

April 15, 2020

Ms. Shannon Anderson
Acting Director
Powder River Basin Resource Council
934 N. Main Street
Sheridan, WY 82801

Re: Review of Brook Mine Application – Rounds 8 to 12

Dear Ms. Anderson,

As you have requested, we have reviewed the relevant sections of the mine application and related documents for the proposed Brook Mine as it relates to mine subsidence potential and their effects and geotechnical reclamation issues. These materials include those prepared by Ramaco, WCC Engineering, Agapito Associates, Inc., Wyoming Department of Environmental Quality, and Engineering Analytics, Inc. A list of these documents reviewed for this report are provided in Attachment A.

The report covers Rounds 8 through 12. The 8th round submittal by Ramaco was mainly in response to the Wyoming Environmental Quality Council (EQC) comments who deemed the 7th application as inadequate for a number of issues. Rounds 9 to 12 submitted by Ramaco addressed further comments made by the Wyoming Department of Environmental Quality (DEQ). DEQ has determined the Round 12 mine application to be complete. Despite the Findings of Fact and Conclusions of Law by EQC, and having gone through 12 rounds of review with the Department of Environmental Quality, Ramaco only made a token effort to address the mine subsidence issues of the mine design. Because of the limited additional geotechnical information gathered by Ramaco, Ramaco's consultant Agapito Associates Inc. (AAI) of Colorado provides a Subsidence Control Plan (SCP) for only one seam and only the first area (TR-1) to be highwall mined, and even in this SCP analysis, there is a number of disclaimers/qualifiers to their findings. For example, AAI "DISCLAIMER:" … states … **"conclusions expressed herein are based on the facts currently available within the limits of existing data, scope of work, budget, and schedule.** Supporting data and information relied upon during the course of this investigation and used to prepare this report have been obtained from Ramaco Carbon records and files, available published reports and literature, personal communication with Ramaco Carbon staff, and other information sources. **Agapito Associates, Inc. makes no representation or warranty as to the accuracy of the data supplied and used in the development of this report"**(highlights added). This disclaimer is understandable given

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that only one additional hole was drilled and sampled with geotechnical testing for only one seam (the non-split Carney Seam). Yet, even with AAI's qualification for the design of only the TR-1 area (68 acres), Ramaco applies for in the application to allow highwall mining of a total of 1,960 acres with all, or the vast majority, of the land with proposed multi-seam mining.

It is acknowledged that Ramaco has hired a mining/geotechnical consultant, AAI, to address subsidence potential issues since the EQC's recent rejection of the Brook Mine application. AAI has provided responsive mine design analyses and associated subsidence potential analyses. These reported analyses, however, do not meet the necessary standard for review or provide sufficient assurances that significant subsidence will not occur from the highwall mining. Consequently, because there has been no substantive change in the Rounds 8 to 12 submittals, the main opinions provided in our report to you on January 23, 2017 have remained unchanged. The January 23, 2017 report is attached for your reference. See Attachment B.

A detailed review of the submitted AAI's report, the mining plan, the Subsidence Control Plan (SCP), and surface reclamation is given below.

PROPOSED MINING

The proposed highwall mining (HWM) methodology has been discussed in MEA, 2017. Since this report, the current application calls for the strip mining of the Monarch seam and no planned mining of the Monarch seam (MP1-2.2, MP.4.4, MP.4.4.1, and MP.4.6). In other words, only the Carney Coal is planned to be underground mined at this time. Another significant change from the Round 7 application is the abandonment of the most eastern highwall mining area, formerly TR-1 (see Figure 4.3, MEA, 2017). As pointed out by MEA during Round 7, HWM in this area was not well thought out. It contains significant mine spoil from previous Big Horn strip mining operations, and consequently, was not practical.

The new proposed HWM TR-1 area consists of only one block (in lieu Blocks 3 and 4 formerly TR-2, see MEA, 2017). The new mine plan is shown in Figure 2. Comparing Figure 4.3 (MEA, 2017) to Figure 2, it appears the changes in the mine plan only pertain to the old TR-1 and TR-2 areas. Consequently, the HWM areas which were Blocks 9 and 16 in Figure 4.3 still abut against old workings with minimum barrier coal of 0 to 70 ft. and consequently result in potentially flooding from the old workings to the south especially considering the likely inaccuracies of the mine map of the old works. Based on historical mapping, the floor depths in the minimum barrier areas are about 87 to 115 ft. in the new TR-4B, 5, and 7 areas. See Figure 2. Based on various empirical relationships on the minimum confirmed barrier thickness, this barrier should be at least about 55 to 110 ft. (Koehler and Tadolini, 1995), and therefore all areas (TR-4B, 5, and 7) would exceed the minimum confirmed barrier width depending on what criterion was used. Moreover, MSHA requires a minimum coal barrier width of 200 ft. for underground mining next to abandoned workings (30 CFR 75.388).

The general information on the room and pillar dimensions and panel, and coal barrier widths has remained unchanged. Only for new TR-1 area was more specific HWM design criteria proposed for the unsplit Carney Seam. For the maximum recommended extraction with a mined coal height of 14 ft. (Add. MP-6-42) and room width of 11.5 ft. (Add. MP-6-36) AAI determined the following (Add. MP-6-47).

Panel	Design Depth	Web Pillar Width	Panel Extraction	Tributary Pressure
1	266 ft.	14.1 ft.	45%	544 psi
2	279 ft.	14.2 ft.	45%	571 psi
3	333 ft.	17.9 ft.	39%	614 psi
4	338 ft.	18.3 ft.	39%	623 psi

AAI, however, assumed that only the Carney Seam will be mined in TR-1. For the TR-1 area, both the overlying Monarch and underlying Masters coal seams have mineable thicknesses (see Table 4.1, Block 4, MEA, 2017). Even though these seams are not currently planned to be underground mined, no comment was made by AAI on design of multiple seams. It should also be noted that no consideration is made in the design for the pillar loading imposed by the planned stockpiles of mine spoils depicted in the Exhibit MP.1-2. This exhibit shows the stockpiles to be as wide as about 500 ft. and as long as about 1,500 ft. These stockpiles could reach significant heights with no restriction.

GEOTECHNICAL DRILLING AND TESTING

The proposed geotechnical drilling and testing after Round 7 for the proposed future underground mining areas has generally become less stringent and more ambiguous as modifications were made to the permit application by Ramaco. In its final form, Ramaco states "in future highwall mining blocks outside the study (TR-1) area, additional hole(s) covering a similar area are appropriate, with a similar suite of tests" ... in the roof, coal and floor of the Carney Seam as has been performed in the TR-1 panel (Ramaco Responses to Round 8 DEQ Memorandum of Deficiencies dated January 14, 2019). Ramaco further stated in the permit application that "prior to initiation of auger mining activity, samples will be collected and strength testing will be conducted … in order to satisfy the requirements of the MSHA ground control plan which must be approved prior to mining." These test results and analysis "will be provided to WDEQ/LQD" prior to mining.

In Appendix D5 – Topography, Geology & Overburden Assessment dated 12/19 prepared by WWC Engineering, it states tensile strength results will be used to size web pillars and barrier pillars to achieve SF set by MSHA ground control plan to conduct mining and minimize the risk of subsidence.

Below are the issues related to the above proposed geotechnical drilling and testing in the mine application.

1. The one geotechnical boring which was done in the TR-1 area, which is proposed first area to be highwall mined. This boring indicated the roof and floor contains anomalous rock conditions compared to other borings drilled in the application area. Therefore, applying these rock conditions and associated test data to all of the application areas or, for the matter, all of TR-1 appears inappropriate.

2. The promised number of geotechnical test holes and testing on what strata per HWM area is vague and undefinable as given in the above statements and in the application. Therefore, these geotechnical promises are not enforceable.

3. Specific types of geomechanical testing are given but they will provide a deficient assessment of long-term strength and should include the consolidated drained triaxial tests which were originally promised after Round 7. Also, no Atterberg Limits are stipulated which really assist in rock classification, the potential for softening, and softened strength parameter values.

4. Use of the tensile strength for determining the pillar strength by Ramaco as noted above is not appropriate and should not be allowed.

5. The exploration and testing program proposed in the mine application assumes only the Carney seam will be mined without any geotechnical provisions if multi-seam mining were to occur in the future.

6. DEQ should regulate the number of holes and testing required, not the mining company. Undefinable information supplied by Ramaco where future data and analysis are promised at an undetermined time prior to mining and without noted approval of a SCP by DEQ. Moreover, the data and analyses promised are related to MSHA requirements which are not focused on surface subsidence above HWM areas.

MINE STABILITY ANALYSIS

Ramaco's Approach

In response to EQC's Finding of Facts and Conclusions of Law – Round 7, Ramaco cites "Brook plans to do the necessary engineering work Dr. Marino suggests as part of the ground control plan Transcript – Barron testimony, pp. 1532-1533 (Comment EQC 60 – Round 7)". This was not done. The main concern is the assessment of the long term stability of the mine design analysis to prevent mine subsidence. In an effort to ensure that the "necessary engineering work" was done, long term stability design guidelines were provided and for convenience are provided in Attachment C. Instead, Ramaco ignored significant portions of these guidelines. Ramaco hired and directed AAI to perform design analyses for mining of one seam in one area (TR-1), see Figure 3. AAI utilized in design only one test hole in the TR-1 area with insufficient testing. Using this provisional design, however, Ramaco applied for a permit to mine the whole proposed mining area. The area of HWM of one seam that AAI provisionally designed for was about 68 acres compared to a total of about 1,960 acres of HWM applied for. Since no engineering analysis was performed for the multi-seam HWM condition, the submitted mine plan was absent of any criteria on the allowable thickness of the interburden for the different lithologic and mining conditions.

Because AAI's design report is incomplete in many respects, a complete critical expert review was not possible. This includes:

- No codified rock classification for understanding material types.
- Point data not provided for Carney Coal Thickness with contours of 0.5 ft. (see AAI Figure 3).
- Point data not provided for Carney Coal floor elevations with contours to 1.0 ft. (see AAI Figure 4).
- AAI states: "Unmapped faults may exist that complicate the seam structure" (Add. MP-6-24), but are not addressed in the design.
- Joint (fracture) pattern assumed in UDEC modeling used to check for mine instability not given (Add. MP-6-55).
- Joint slippage properties assumed in UDEC modeling used to check for mine instability not given (Add. MP-6-56).
- No reference for the assumed "western coal" strength.

- No long term strength data for the mine roof or floor.
- No analysis provided on how the floor stability was determined to be adequate (Add. MP-6-38,39).

In the analysis below, the fine-grained rock overburden and floor in the test hole (Boring 2017-4) done for the design of the TR-1 HWM area are classified as mudstone and is assumed as such in AAI stability analysis. It is unreasonable, however, to assume a roof and floor containing mudstone as the worst case condition when there is a significant amount of roof and floor material described as claystone in the other borings submitted in the application, especially without running, at a minimum, Atterberg Limits to verify the rock plasticity. These fine-grained clastic rocks are very difficult to properly identify without this testing (Marino and Osouli, 2012).

Below is the review of limited AAI mine design analyses against mine roof, pillar and floor failure based on the information available in the AAI report. See Figure 3.

Roof Stability Design Analysis

For the TR-1 area, AAI analyzes the mine roof short term stability for highwall mining. Because of the reported weak mudstone beds, AAI recommended leaving 1 ft. of coal in place to avoid short term collapse of the more immediate roof rock, although the more immediate mudstone is likely to collapse in the long term. AAI calculated a roof stand up time of only 77 days (Add. MP-6-38). AAI noted, however, that above the 6 ft. of strata of essentially mudstone sequences is a “18+ ft.-thick sequence of moderately strong sandstone that may be sufficiently competent to bridge across the 11.5 ft. opening width.” In view of the reported overburden geology across application area as discussed in MEA, 2017, these sandstone beds are laterally discontinuous and thus, should not be relied upon as being omnipresent. Furthermore, evidence that sandstone is sufficiently present with adequate capacity in the overburden is not borne out by the massive amount of pit subsidence over the adjacent old works which are in the Carney Seam (see MEA, 2017).

Pillar Stability Design Analysis

For HWM in TR-1, AAI offers two designs: one with a stability factor (SF) of 1.6, and another where SF is 1.8 “to reduce the likelihood of pillar failure” (Add. MP-6-39). SF is calculated using the program ARMPS-HWM. This design methodology was developed for bituminous coal fields with web pillar heights of 7 ft. or less. The application conditions, however, fall outside this criteria. The Carney Seam is sub-bituminous coal and is 16-17 ft. thick in the TR-1 area reaching 18+ ft.-thick across the application area (see Table 4.1, MEA, 2017).

As stated by AAI, “Mark and Barton (1997) concluded that laboratory test results (typically from tests on 2-3 in. core) are a poor predictor of in-situ pillar performance, and that a constant in-situ coal strength of 900 psi (when considering 36” or greater cubes of inplace coal) produce better results” (Add. MP-6-40). However, AAI correctly recognized, as noted in MEA, 2017, that bituminous coal would have a higher strength than the Carney sub-bituminous coal. Therefore, AAI assumed in-situ coal strength of 762 psi. Rationale to arrive at 762 psi, however, defies logic. AAI justified the reduction from 900 psi to 762 psi for sub-bituminous coal based on the reduction of an unsubstantiated laboratory compressive strength for “western coal” to that for the Carney Seam (from Test Hole 2017-4). Yet by their own admission, lab tests do not relate to the larger in-situ cube strength. In addition, it is not known if the “western coal” strength was from bituminous or sub-bituminous coal or how it was derived. Moreover, AAI then claims the derived strength of 762 psi is “more conservative” without explanation (Add. MP-6-40).

Roof/Floor Bearing Design Analysis

AAI describes the immediate 6 ft. of the Carney roof as weak carbonaceous mudstone to mudstone which becomes sandy towards the top (Add. MP-6-33, 75-77). The carbonaceous mudstone was found to be non-durable with Slake Durability Index (SDI) of only 11.8% (Add. MP-6-32). As noted above, AAI calculated this roof’s “stand up time” to be 77 days. Because of the concern for fallout during mining, however, AAI recommended leaving 1 ft. of sub-bituminous coal in the roof. However, whether or not this coal thickness can be remotely controlled or maintained if the coal thins or undulates, and how long the coal (without bolting with mesh) will remain are suspect. Caving in the long or short term of the weak immediate roof adversely affects the roof’s ability to laterally restrain these mudstone strata above the pillar from roof squeeze. Based on the pillar design at SF=1.6, web pillar width to weak roof thickness ratio $(\frac{W_p}{h})$ would range from 2.35 to 3.0 for Test Hole 2017-4, and would be clearly susceptible to roof squeeze. No roof bearing analysis was performed by AAI.

The upper almost 2 ft. of the floor is described as carbonaceous mudstone which AAI states “is not expected to provide adequate floor conditions in a wet environment.” This non-durable immediate floor had a reported SDI of only 22.4% with a very high natural moisture content of 18%. This material is underlain with at least 14 ft. of mudstone which is described as “weak, plastic mudstone which would form a very poor floor.” This rock tested to be fairly non-durable with SDI’s of 59.7% and 71% and with a high natural moisture content of 12.8%

(Add. MP-6-32-33)[1]. At the termination of the test hole, these mudstone sequence was at least about 14 ft. thick.

AAI also recommended leaving 1 ft. of sub-bituminous coal cover as a result of their concern for the floor conditions. This may assist in the immediate short term with HWM trafficability, if it can be done, but provides little benefit over time to restrain floor heaving. Given these floor conditions, $\frac{W_p}{h}$ is no greater than 1.3 for Test Hole 2017-4 and thus clearly more susceptible to pillar punching.

As noted above, AAI recommended the use of 1 ft. of roof and floor coal in their report. However, they later stated in response to a DEQ Deficiency Letter (Ramaco response to DEQ Memorandum dated December 27, 2018 by R. Barney) that the need for this roof and floor coal was not expected to be the normal condition. Consequently, an extraction height of 16 ft. should be considered in lieu of 14 ft. in the TR-1 area. Therefore, AAI analyses which assume an extraction height of 14 ft. are not most representative of what is expected in the TR-1 area.

AAI only performed a bearing capacity analysis on the mine floor. AAI stated "the bearing capacity stability factor of the CMS (carbonaceous mudstone) floor layer was calculated to be greater than 2" (Add. MP-6-39). AAI appears to erroneously ignore any failure through the underlying "weak, plastic mudstone." Moreover, no details of this important analysis are provided for review. However, it is stated that the bearing capacity analysis was done considering the cohesion and internal friction angle values for each layer as given in AAI Table 8. For the floor materials, AAI assumed cohesion and friction values of 243-553 psi and 20.9-29.2° respectively.

From our experience with mudstone floors, the strength values assumed by AAI for the fully softened and unsoftened conditions are too great (Marino and Osouli, 2012). AAI described these mudstones being weak and plastic yet while the friction angle values are reasonable, these assumed cohesion values, which are the dominant factor in determining the AAI calculated bearing capacity are too high. In fact, from a significant amount of testing we have done, the cohesion can drop to essentially zero in the fully softened state leaving only friction to resist bearing failure[2]. In the softened state, the bearing capacity of the non-durable mine floor with initial moisture contents of about 13% (as reported by AAI) can be easily below the design pillar pressures of 544 psi to 623 psi noted above. Moreover, it is unknown how these strength parameter values were specifically extrapolated by AAI since

[1] From our experience, given a reported material moisture content of about 13% these reported SDI appear high.

[2] Although the extraction ratio proposed by AAI is below 50%, significant softening is expected below the web pillars because they only reach widths of about 18 ft. and $\frac{W_p}{h}$ is no greater than 1.3

they were not directly measured from any reported laboratory tests performed yet very specific. And, it is unknown why AAI only considered shearing in the top 1.8 ft. of carbonaceous mudstone (Add. MP-6-39) and ignored deeper seated failure into the “weak, plastic mudstone,” which is likely the more critical condition.

In fact, the UDEC modeling used to “check roof and floor for stability, and detect other potential failure mechanisms” considered the mudstone floor to also have a tensile strength ranging from 76 to 89 psi per layer in addition to the unrealistic cohesion, thereby further increasing the floor strength and improving stability. Note, in the unreported bearing capacity analysis, AAI stated no tensile strength was assumed. Use of a tensile strength in unsoftened to softened mudstone floor is completely unrealistic and reduces any indicated instability results.

As can be seen from the above, AAI using unreported bearing capacity methodology, arrived at acceptable floor stability using unrealistic floor strengths even in the unsoftened state. AAI did not consider the much weaker moisture softened condition despite moisture deterioration potential indicated by their only durability tests.

This floor will most likely be exposed to groundwater as a result of a number of factors:

- Even if a 1 ft. coal cover is considered, groundwater will seep through exacerbated by cracking in the coal from any significant floor heave from pillar punching and swell of floor materials from exposure to moisture.

- Groundwater exposure from unmapped faulting or shear zones, roof collapse uncovering beds seeping groundwater, surface runoff through complete chimney collapse events and the HWM opening, and flooding from adjacent old works.

AAI reported “It is expected that aquifers are associated with the coal seam(s) and adjacent sandstones with intervening shales and clays inhibiting vertical movement. Some groundwater inflows can be expected during highwall mining operations” (Add. MP-6-24,25).

AAI also investigated the potential for “cascading pillar failure,” or in other words, the potential of an outward progressive failure from localized pillar crushing or compression. This was analyzed using a program called LA Model. This software calculates the transfer of stress to adjacent previously unyielded pillars through bridging (or arching) in the roof overburden. However, the LA Model does not account for roof/floor bearing deformations and therefore this analysis is not valid given the site conditions. Moreover, given the reported mudstone roof and floor, it is not reasonable to consider there is not significant yielding of roof/floor which affects the outward progression of pillar failure especially since the failure is most likely in bearing not in the pillar.

SUBSIDENCE ANALYSIS

Surface subsidence is an expression of an underlying mine collapse. Over room-and-pillar workings subsidence develops in the form of sinkholes (aka pits) and bowl-shaped depressions (aka sags over room-and-pillar mines). Pits and smaller sags are caused by chimney roof failure above a mine opening, whereas larger sags result from yielding of a number of pillars from outright crushing, or roof/floor deformation (see UPDATE 14).

Pit Subsidence

The potential for pit or chimney subsidence was evaluated by AAI for only the TR-1 area for highwall mining of only the Carney seam. AAI concluded "the risk of sinkhole subsidence associated with highwall mining at the Brook Mine is considered low, but cannot be dismissed entirely, particularly in the shallower cover areas near the box cut (or highwall)." This opinion was in part based on a study of pit development in Colorado performed by Matheson, 1990, who developed the following equation to estimate the probability of pit subsidence.

$$P=1{,}516\left(\frac{D}{H}\right)^{-4.0}\quad\left(\text{for }\frac{D}{H}\geq 6.3\right)$$

where: D = depth of floor of opening
H = mining height
P = probability of pit subsidence

This probability model by Matheson was not applied by AAI as the data relied upon for this model excluded the case data AAI used in their analysis for sinkhole development potential above the proposed Brook Mine. Consequently, the above equation is not applicable. AAI used Matheson's excluded Colorado case because it better represented the room-and-pillar conditions proposed at the Brook Mine. From the excluded case data of 82 observed sinkholes, AAI determined the 100% probability was when $\frac{D}{H}$ equaled 2.7. Also, the Matheson probability is somewhat a misnomer as it actually is based on the frequency of subsidence occurrences per unit area.

With the use of the Matheson case data, AAI determined the frequency of observable sinkholes per unit area for different mine depth ranges. AAI added similar results were obtained when examining the observable subsidence over the adjacent Carney, KOOL and Monarch mines to the Brook Mine. With the use of these depth related frequencies, AAI determined that 7 sinkholes may develop using the Matheson Model to a depth of 178 ft. and none should develop beyond this depth. This, however, is only for the TR-1 area where the extraction height was erroneously assumed at 14 ft. AAI also noted 7 sinkholes was considered a conservative estimate since the HWM entry width of 11.5 ft. of roof span, was less compared to the Matheson studied mined-out area.

In performing a "probability" analysis of estimated number of sinkholes in the TR-1 area, AAI adopts the Matheson $\frac{D}{H}$ model. However, in the Matheson reference used by AAI, the definition for D is mis-stated and thus, inappropriately applied by AAI in their sinkhole analyses. D is the depth to the coal seam or the overburden thickness as indicated to Figure 4 and Table 3 of Matheson, 1990[3]. Also, this definition of D does not intuitively make sense and is not traditionally defined that way. Moreover, given that the "normal condition" for TR-1 is not to leave coal in the roof and floor, H will be 16 ft. not 14 ft. as assumed. Therefore, Table 9 in the AAI report was redone using the appropriate values and is provided in Table 1. This is analysis results in a predicted 16 sinkhole (distinct subsidence) features compared to 7 estimated by AAI. For the remaining HWM application area, these calculations with assumptions by HWM panel are given in Tables 2 to 15. Using this chimney subsidence prediction methodology by AAI, 2,680 sinkholes (1.4 subsidence events/acre) are estimated over the entire proposed HWM area. With this number of events, it is clearly not an unplanned subsidence plan.

Even though the AAI chimney subsidence prediction method appears inappropriate and an excessive over-estimate on the frequency of events, it does not provide any confidence that future chimney subsidence is not problematic. Moreover, the risk of surface subsidence from HWM entry roof collapse should also account for the following factors.

1. The less distinctive chimney features or sags will not be noticeable from the aerial photography used in the AAI analysis count subsidence events. In other words, the subsidence count made by AAI would be only for the more dramatic features which can be seen from high elevation aerial images. It would not include all the smaller pits or smaller to larger sags or troughs. Therefore, the prediction of "probability" of chimney subsidence (pits and smaller sags) underestimates the frequency of subsidence events.

2. In the current application, the Monarch seam is no longer highwall mined. It is only planned to be surface mined throughout the application area (Figure MP-6.1-1). Based on Figures 4.3, 4.1, to 4.24 in the 2017 MEA Report. The Monarch seam is shown present in Mine Blocks 13, 17, and 20. Surface mining in these areas will remove at least up to 35 to 105 ft. of overburden, the vast majority of which is rock and will be replaced with mine spoil. The reduction of the rock overburden in these

[3] D is mis-defined in the text of the paper. Note, if D were taken as floor depth, the overburden thickness to mined height would not be 2.7 at < 25 ft. depth.

areas with clayey mine spoil will clearly increase the risk of surface subsidence from HWM entry collapse from the underground mined Carney.

3. AAI chimney subsidence analysis does not account for the “portal” subsidence at the tapered back highwall. Also, data on how closure of the HWM openings will be addressed is not provided, for example, will the mine spoil be merely dumped in front of these HWM openings, as implied.

4. The method of “probability” used by AAI given above for sinkhole subsidence for HWM of the Carney seam in the TR-1 area is also in conflict with the methodology provided by Ramaco in the Subsidence Control Plan (SCP) for the overall application area. This methodology is discussed in detail in MEA, 2017. The methodology used by Ramaco recognizes the importance of other parameters in prediction of chimney subsidence which is ignored by the “probability” criteria used by AAI. Chimney prediction methodology (e.g., Piggott and Eynon, 1977, Garrad and Taylor, 1988, Whittaker and Reddish, 1989, and Dyne, 1998) typically considers at a minimum the bulking (volume expansion) from the caving of intact roof rock, the extraction height, width of intersecting mine openings and the repose angle or the spread of the caved material into mine openings. This was exemplified by Ramaco in Figure MP-6.2-4 (see Figure 4).

Sag Subsidence

AAI states that “the highwall mining plan (for the Carney seam in the TR-1 area) for the Brook Mine has been developed to minimize the likelihood of trough (sag) subsidence”… (Add. MP-6-62). As noted above, sag subsidence from pillar bearing failures into the “weak” “plastic” mudstone floor (and possibly roof) appears likely. This type of failure would cause sag or trough subsidence in addition to smaller sags from chimney subsidence. From a study performed by the USGS in the project area, Dunrud and Osterwald 1980 illustrated both trough and pit subsidence from the area, which is shown in Figure 5. Note, the USGS illustration depicts pit/sinkhole subsidence inside a larger sag. This indicates at shallower depths where sinkholes occur, massive pillar related failure would also occur. In addition to outright crushing, pillar failure can be induced by excessive deformation in the weak adjacent mudstone. Moreover, AAI notes that pillar failure can cause spontaneous combustion (Add. MP-6-21). Coal fires are not uncommon in the area and can result in additional subsidence and possibly other environmental concerns. Moreover, in review of the mine application, the Wyoming Land Quality Division (LQD) noted in a Memorandum dated December 27, 2018 that “leaving coal in the roof and the floor (as proposed by AAI above) there may be increased chance for spontaneous combustion of coal and coal fires. Coal fires could potentially weaken pillars.”

SUBSIDENCE REMEDIATION

In the mine application, Ramaco discussed their remediation plan if chimney (sinkhole) subsidence would result over the proposed HWM area. Ramaco stated that areas highwall mined will be “monitored for at least 6 months after highwall mining of the individual areas are completed. If there is no evidence of subsidence, then the monitoring of the area will be discontinued” … “Backfill” of the detected subsidence will however only be “performed on a selective/as-needed basis.” The select subsidences which will be remediated will be only those which do not exhibit “self-healing” and there is the introduction of oxygen or surface water. Ramaco notes it “will continue to perform remediation on any subsidence, detected during or subsequent to the 6 month monitoring period, until bond release is approved” (MP-6.3 and MP-6.4).

The above remediation plan does not require any monitoring above HWM areas beyond 6 months, and only remediates those which are not “self-healing” in lieu of remediating all sinkholes. Moreover, “self-healing” is not sufficiently defined. If the sinkhole collects water, would that mean it has “self-healed”? In lieu immediately “backfilling” the pit, is there a waiting period to determine if it will “self-heal”? It is also unclear how the pit will be backfilled.

From our experience, at a minimum, backfilling a subsidence event in an open field should include compaction of the subsidence bottom and then compaction of the subsequent lifts of select fill placed in depression. The backfilling should continue to at least meet the natural surrounding surface contour, and as noted in the application, be covered with topsoil that supports the vegetation demand. Although not even considered in the Ramaco SCP, remediation should also apply to trough or sags which have significant depth affecting surface drainage.

It should be noted that the Ramaco subsidence remediation plan falls way short of the reclamation efforts performed by the State on the subsidence features which have resulted above the adjacent abandoned Carney Mine No. 44 (PHC Reclamation, 2006).

Criteria is recommended by AAI for “any surface structures or other facilities” that would require protection from subsidence for HWM. Their report states “AAI considers a 50 ft. offset and an angle of critical deformation of 25° to be appropriate.” Under the most likely site conditions, this criteria appears to be acceptable.

SURFACE RECLAMATION

In Section RP.3.3 entitled Post Mine Slope Analysis, the reclaimed land slopes are reported from 0 to greater than 45° and are in fact, noted to 69.5° (Table RP.3-1) without distinction of which slopes are native or reclaimed. It is not known whether the greater slopes are in native rock or highwall areas, or native or reclaimed soil slopes. Further, there is no discussion of how the reclaimed slope will be constructed to prevent landsliding conditions, or analysis of the stability of such slopes. Given that the majority of the mine spoil will likely consist of rubblized claystone, only gentle slopes should be tolerated.

DEQ OVERSIGHT

In Round 7, DEQ admitted it has only limited expertise in mine subsidence engineering. This explained the blatantly inadequate review of the subsidence engineering aspects of the Brook Mine Application. In lieu of soliciting an expert in mine subsidence, the agency had in effect acted as a “pass through” in determining that the application was technically complete in this respect.

Recognizing that they did not have sufficient expertise to evaluate the subsidence engineering aspects of the Brook Mine application, after Round 7 DEQ contracted with Engineering Analytics, Inc. (EAI). Engineering Analytics scope of work was “to provide an evaluation of a subsidence sampling and analysis plan” of the Brook Mine Submittals and to provide “evaluation of the adequacy of Brook Mine’s submittal in addressing each subsidence finding in the EQC order” (EAI Technical Memorandum dated June 19, 2018 and DEQ Memorandum dated October 16, 2018).

Accordingly, Mr. Dan Overton of Engineering Analytics notes in a Technical Memorandum dated June 29, 2018 that the EQC recommended “a commitment by the Brook Mine to do the appropriate studies per Dr. Marino’s suggestions to move towards a proper mine subsidence plan (Findings No. 59 and 60)”. These suggestions and concerns were spelled out in the 2017 MEA Report (see Attachment B) and the document entitled: Room and Pillar Recommendations Against Surface Subsidence – Proposed Brook Mine, Sheridan, Wyoming (see Attachment C) and in an initial review of items from the Round 8 application provided to DEQ in an email dated December 31, 2018. The MEA report and recommendations documents were in the possession of the DEQ in addition to the EQC prior to their written order. Based on the review of the most recent Brook Mine application documents, which was deemed complete, our concerns provided in these above documents were substantially ignored. Furthermore, there is no evidence, other than possibly MEA 2017, that these documents were even received or considered by Engineering Analytics, despite EQC findings. Note, there is no reference to any of these documents in any of EAI’s reports.

From review of their Technical Memorandums on the Brook Mine submittals related subsidence issues, Engineering Analytics performed no independent critical analyses of the mine design and associated subsidence potential as performed herein. The vast majority of the EAI Technical Memorandums are a regurgitation and explanation of Ramaco's submittals. However, EAI properly identified the use of consolidated drained triaxial tests in one of the earlier reviews (Technical Memorandum dated June 29, 2018). In this earlier memorandum, EAI states the Brook Mine "subsidence sampling plan is not sufficient as presented" and their plan "remains deficient" in all subsidence related phases. Given the subsequent responses by Ramaco, it is unclear how these major issues were resolved.

Moreover, DEQ provides no geotechnical guidelines or requirements for mine subsidence engineering, such as: minimum required drilling and testing requirements, design methodology, minimum safety or stability factor criteria, protection requirements against subsidence for surface infrastructure, and minimum subsidence remediation requirements. In fact, without such constraints, DEQ had accepted Ramaco explanation that the mine design "will be done in due time."

In terms of subsidence remediation and surface reclamation, DEQ accepted vague and minimal subsidence remediation and reclamation standards. These subsidence standards are far below even the State's own standards as evident by the subsidence reclamation efforts by the State conducted above the adjacent abandoned Mine No. 44.

SUMMARY AND CONCLUSIONS

The findings from this investigation are provided below.

1. Ramaco Resources, Inc. has submitted several rounds of application for the Brook Mine (Rounds 8 to 12). Despite the Wyoming Environmental Quality Council (EQC) comments regarding the technical deficiencies in the applications associated with the subsidence issues of the application from Round 7, Ramaco responded with merely a token effort to address EQC's concerns.

2. Through their consultant, Agapito Associates, Inc. (AAI), Ramaco provided in their Round 8 application more specific mine design criteria for a highwall mining (HWM) of about 68 acres for one coal seam while applying for a total of 1,960 acres of HWM mining. Even their consultant, AAI would not extend their provisional design (with disclaimer) beyond the 68 acre area and just for the unsplit Carney seam with only one new test hole done in supposedly the 68 acre area.

3. Because of lack of specificity, it is unclear how extensive the geotechnical exploration and testing will be, but it clearly lacks long-term stability assessment investigation.

Also unidentifiable, are the types of future mine subsidence engineering analyses that will be performed, and when they will be submitted to DEQ for future HWM areas.

4. In the design analysis, AAI treats the anomalous conditions in one test hole to be uniformly applicable across the entire 68 acre HWM design area. These anomalous conditions depicted in the one test hole and relied upon, may be the cause for AAI disclaimer on their recommendations. In this test hole, the most critical roof/floor conditions are described as mudstone compared to all the other drilled holes in the application which report the presence of claystone – which is considered a more unstable material.

5. Ramaco and AAI do not adequately address the long-term instability of the proposed mine workings that could lead to subsidence. Ramaco and AAI do not account for the significant deterioration of at least mudstone roof and floor materials when exposed to moisture despite their own testing indicating such. In places, the design analysis lacked specificity and thus cannot be critically reviewed. For example, a more critical element of mine instability, which could lead to surface subsidence, are roof/floor bearing failures. AAI only reported a safety factor against failure of only the immediate mudstone floor without any calculations. Further, there was no analysis by AAI of roof bearing failure in the weak mudstone.

6. AAI determines for the TR-1 area that 7 distinctive subsidence features (aka sinkholes) may occur of this HWM area. After correction of this calculation this amount is more than double and over 2,000 such events are expected over the entire proposed HWM area using this methodology.

7. The proposed subsidence remediation by Ramaco in the application is ambiguous and allows for the possibility of many resulting subsidence events to remain untreated. This proposed subsidence remediation plan falls way short of the State's own reclamation standards. Moreover, the surface reclamation plan contains no slope stability analysis despite the steep proposed slopes.

8. With insufficient expertise in mine subsidence engineering, the Department of Environmental Quality (DEQ) has acted as a "pass through" agency through Round 12 and has contracted with Engineering Analytics Inc. (EAI) to review these aspects of the mine application after Round 7.

9. Based on the review of correspondence, DEQ did not provide their subsidence consultant EAI, MEA's suggested guidelines for room-and-pillar design against

subsidence for review (see Attachment B) and other MEA material to the application. The consultant subsidence did not include any significant critical analyses of the submitted application materials.

10. As noted above, the permit application only addresses the highwall mining of the 68 acres of Carney Seam. With application approval, this may provide an administrative mechanism for DEQ to approve remaining underground mining of other mineable seam areas without proper public oversight via a non-significant revision to the permit. This would involve the entire 1,960 acres of proposed highwall mining.

    At a minimum, it is recommended that any highwall mining be removed from the permit until it is reasonably investigated in order not to setup such a precedent of unacceptable protocols. HWM areas should be applied for increments as Significant Revisions as proper subsidence engineering investigation is accomplished. Moreover, in the first 5 years on operation the Brook Mine intends on only surface mining with no highwall mining. This is also consistent with Ramaco's statement in the application that the permit will be renewed every 5 years (Mine Plan prepared by WWC Engineering dated 12/19). Another reason why the HWM application should be delayed and become a Significant Revision is the statement by Ramaco … "AAI agrees that reevaluation should be considered if the ultimate plan involves a greater cutting width, height, or penetration or a lesser production rate than assumed" (Ramaco Response to Round 8 DEQ Memo of Deficiencies dated January 9, 2018).

QUALIFICATIONS

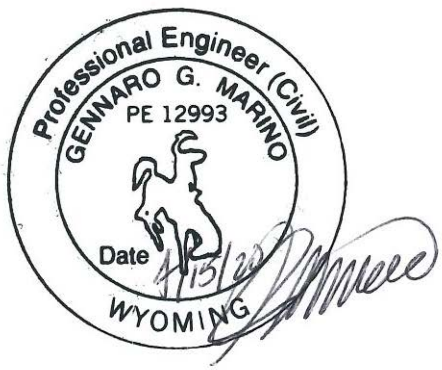
MEA is a leading expert in subsidence engineering from underground mining and from karst. For over 40 years, MEA's staff have provided services across the full scope of subsidence engineering, including significant work in research, site subsidence studies, mine stability design, failure analyses, prediction of subsidence displacement and damage potential, subsidence damage evaluation, foundation design, repair design, and grout stabilization design and monitoring. Being foremost in this field, MEA staff has authored over 100 publications on related topics and have worked in ore fields and karst across the U.S. and Canada. MEA's experience extends to underground mines in limestone, gold, trona, salt, lead/zinc, iron, and coal. Because of our broad reach, MEA is licensed to practice in 27 states.

MEA has also been hired by mining companies and others to provide consulting services on active or new operations for both room-and-pillar and longwall mining in addition to low to high extraction old works. These services are included in those listed above.

Because of the amount of coal mining related work MEA has done, it has designed and developed a cross-hole radar to detect mine voids for cases where mining may exist. Also, from our experience in karst, MEA has researched and developed a TDR system which can be used to detect incipient subsidence beneath a structure.

Having extensively worked on old workings and both low and high extraction active mines, MEA is uniquely qualified and separates itself from other geotechnical and mining engineering companies across the U.S.

If you have any questions about our review of the most recent Brook Mine Application, please contact us.



Sincerely,

Gennaro G. Marino, Ph.D., P.E., D.GE

President

ENCLOSURES:

REFERENCES

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FIGURE 2	NEW PROPOSED MINE PLAN OF THE BROOK MINE SHOWING THE ADJACENT OLD WORKS
FIGURE 3	SKETCHES OF THE THREE PRINCIPAL MODES OF FAILURE OF ROOM-AND-PILLAR MINE WORKINGS WHICH CAN RESULT IN SURFACE SUBSIDENCE
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TABLE 10 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 12 FOR AVERAGE CARNEY THICKNESS

TABLE 11 ESTIMATED NUMBER OF SINKHOLES FOR PANELS 13, 14 AND 15 FOR AVERAGE CARNEY THICKNESS

TABLE 12 ESTIMATED NUMBER OF SINKHOLES FOR PANELS 16 AND 17 FOR AVERAGE CARNEY THICKNESS

TABLE 13 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 18 FOR AVERAGE CARNEY THICKNESS

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TABLE 15 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 20 FOR AVERAGE CARNEY THICKNESS

ATTACHMENT A – Reviewed Documents

ATTACHMENT B – MEA January 23, 2017 Report

ATTACHMENT C – Room and Pillar Design Recommendations Against Surface Subsidence – Proposed Brook Mine, Sheridan, WY

REFERENCES

Dunrud, C. Richard., and Frank W. Osterwald, 1980. Effects of Coal Mine Subsidence in the Sheridan, Wyoming Area. Washington: U.S. Govt. Print. Off.

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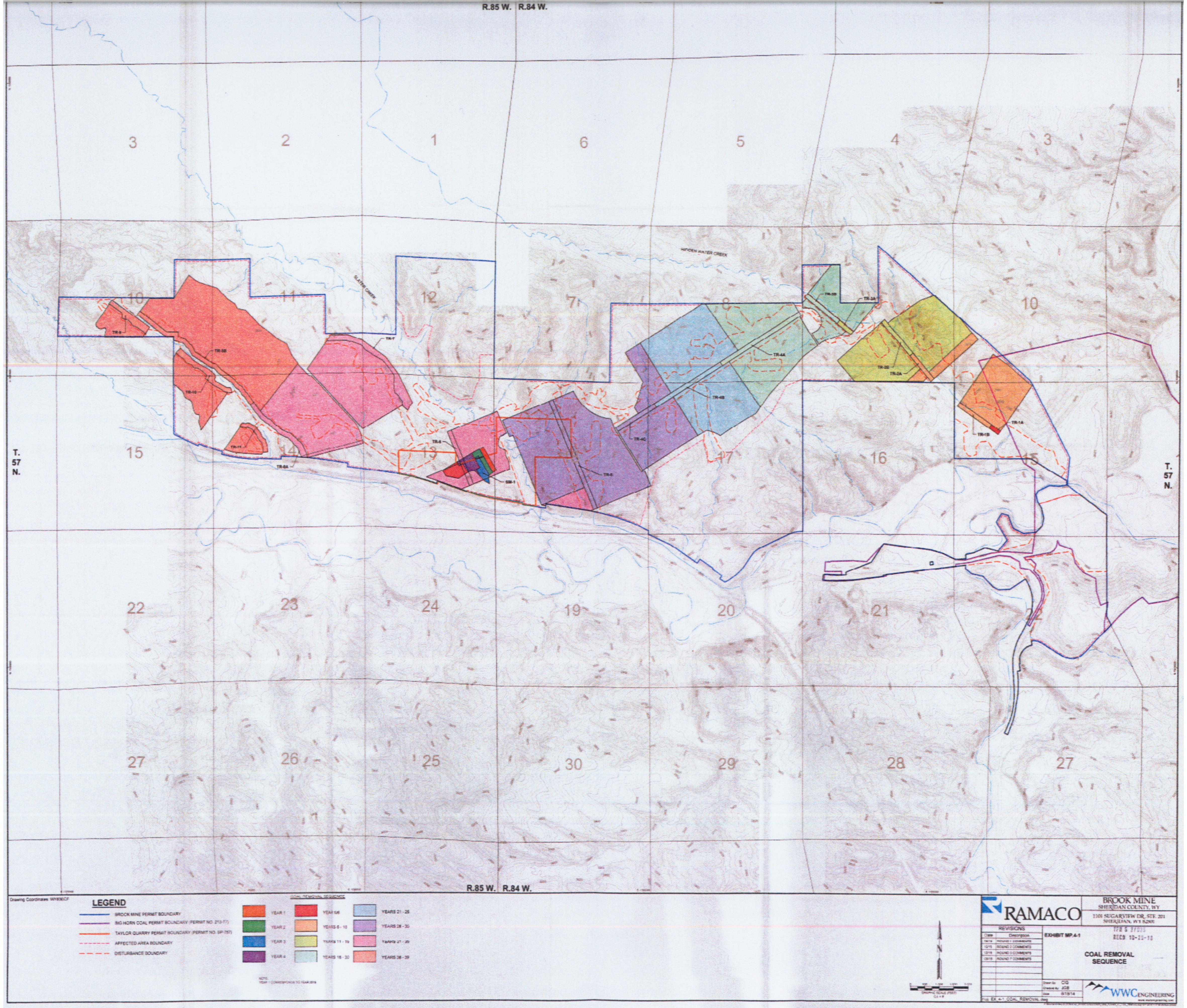


FIGURE 1 NEW PROPOSED MINE PLAN OF THE BROOK MINE SHOWING COAL REMOVAL SEQUENCE

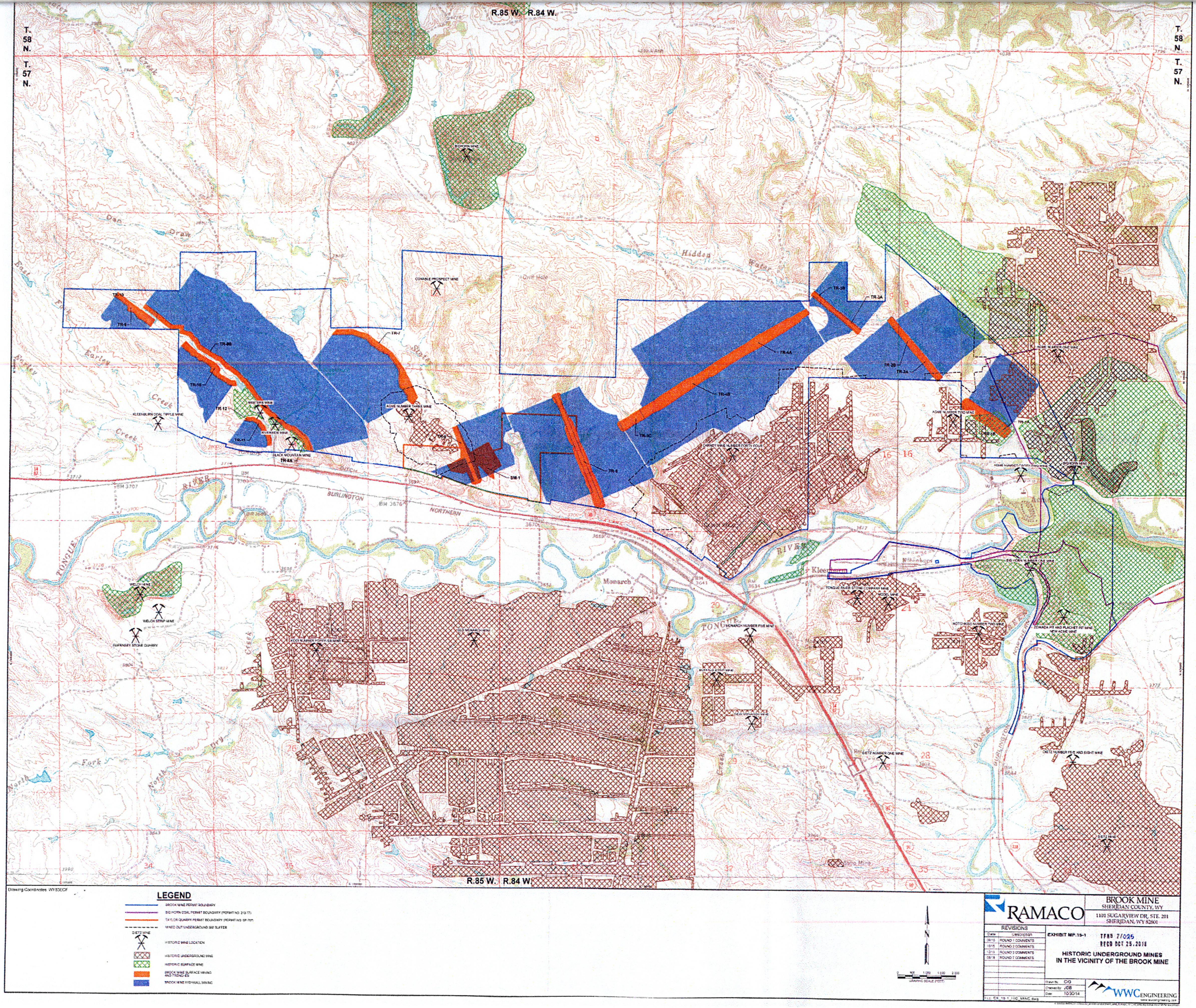
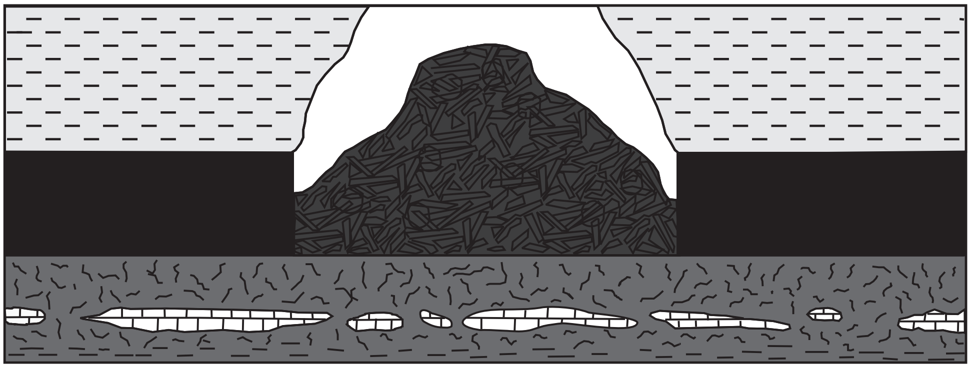
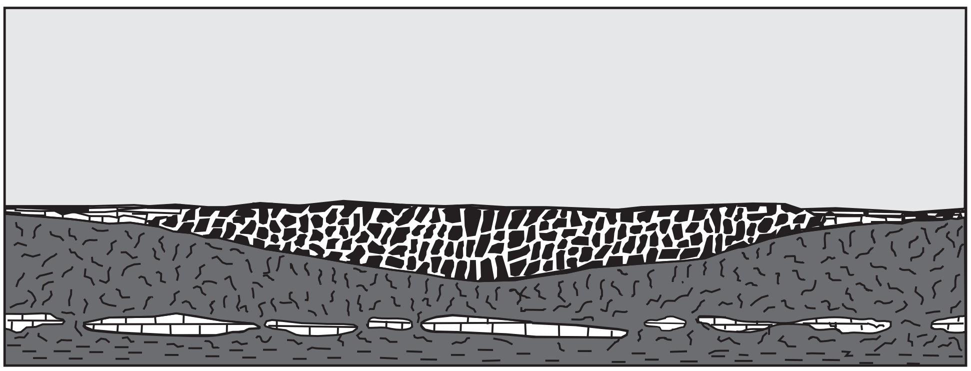


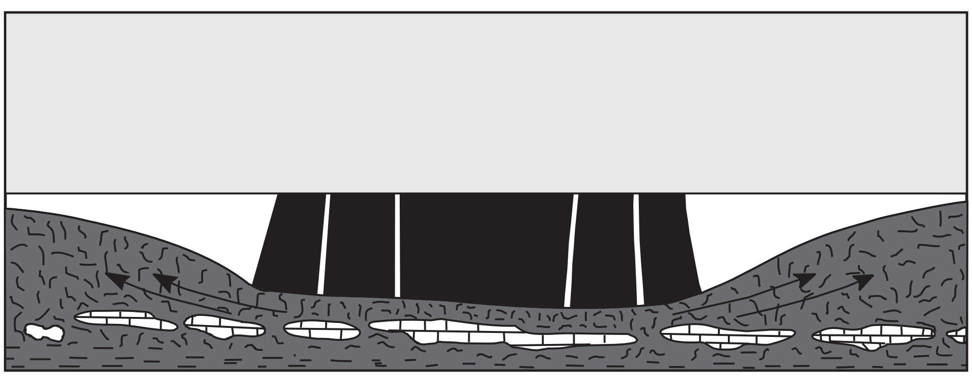
FIGURE 2 NEW PROPOSED MINE PLAN OF THE BROOK MINE SHOWING THE ADJACENT OLD WORKS



ROOF FAILURE ABOVE ROOM



PILLAR CRUSHING



PILLAR PUNCHING

FIGURE 3 SKETCHES OF THE THREE PRINCIPAL MODES OF FAILURE OF ROOM-AND-PILLAR MINE WORKINGS WHICH CAN RESULT IN SURFACE SUBSIDENCE

MEA

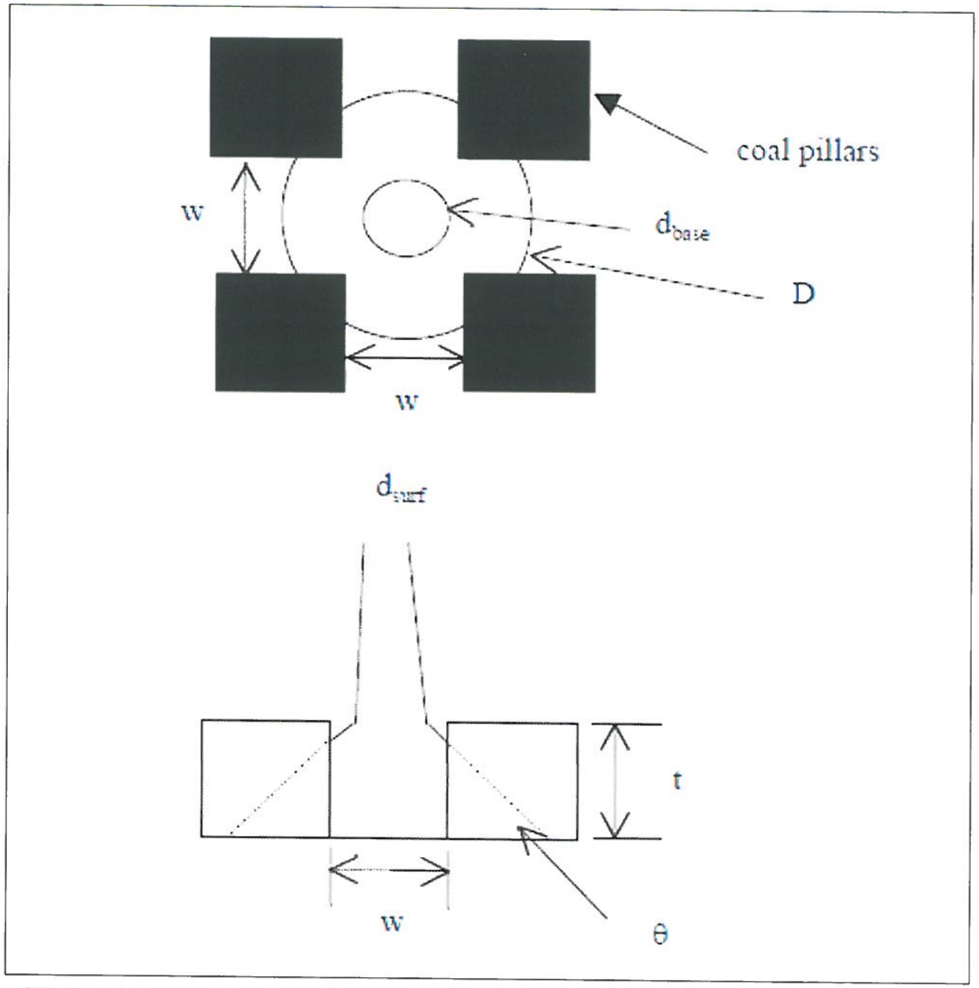


Figure MP-6.2-4 **Explanation of Variables in Equation MP-6.2-1 (Dyne, 1998)**

FIGURE 4 RAMACO ILLUSTRATION SHOWING THE VARIABLES INVOLVED IN DETERMINING CHIMNEY SUBSIDENCE

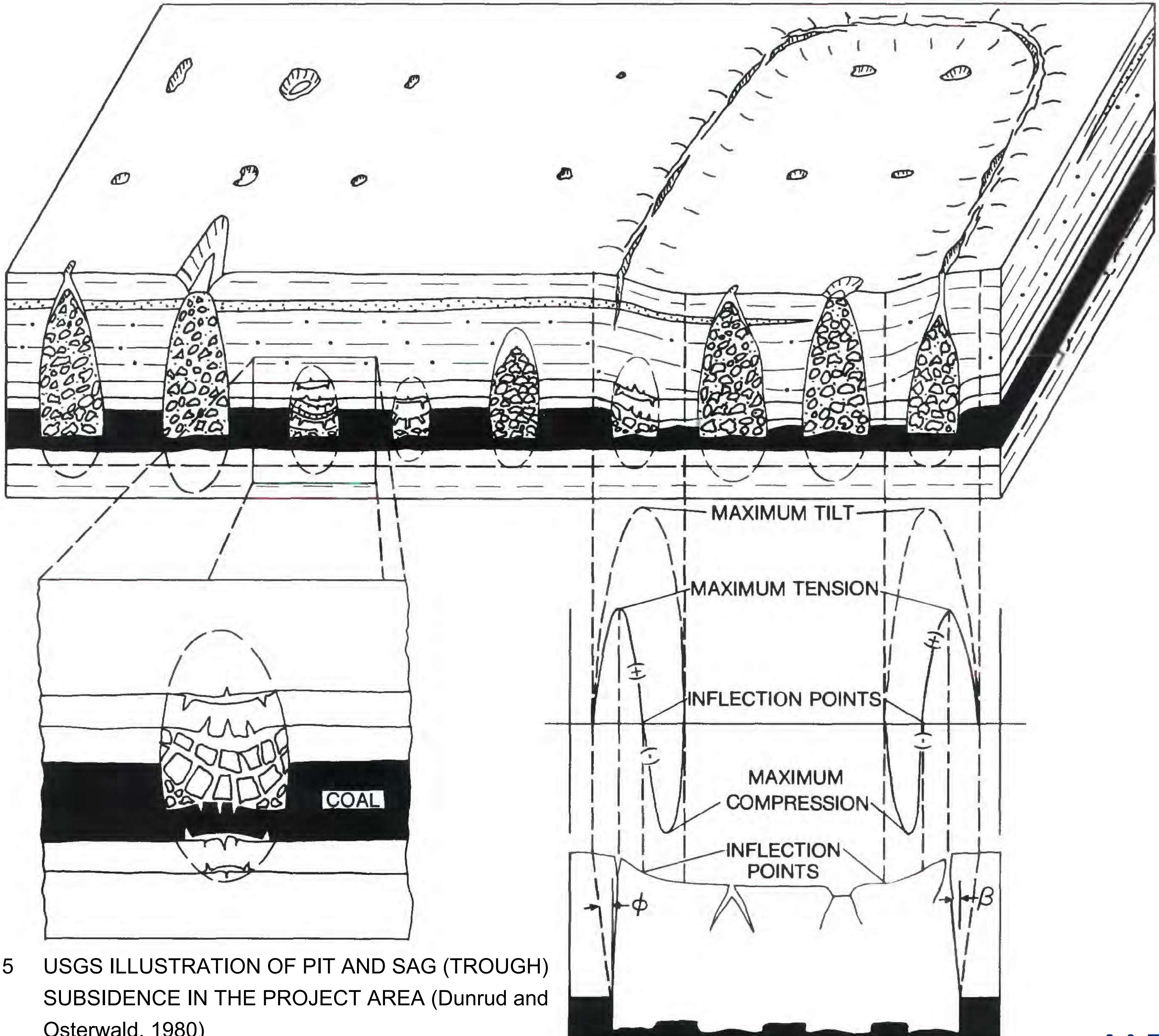


FIGURE 5 USGS ILLUSTRATION OF PIT AND SAG (TROUGH) SUBSIDENCE IN THE PROJECT AREA (Dunrud and Osterwald, 1980)

TABLE 1 REVISED AAI TABLE 9 SUBSIDENCE DATA FROM DEVELOPMENT- ONLY MINES- FOR TR1

Matheson Depth Range (ft)	Brook Mine Depth Range (ft)	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<25	<44	2.7	0.0	17.01	0.0
25-50	44-87	4.1	0.0	8.05	0.0
50-75	87-131	6.9	1.6	5.47	8.7
75-100	131-175	9.6	19.1	0.24	4.6
100-125	175-218	12.4	7.8	0.26	2.0
125-150	218-262	14.6	7.0	0.06	0.4
150-175	262-306	17.9	21.0	0.00	0.0
				Total	16

Notes:
1) TR-1 encompasses Panel 4 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 16ft.

MEA

TABLE 2 CARNEY SEAM TOTAL ACREAGE PER DEPTH INTERVAL, AVERAGE THICKNESS AND MINIMUM THICKNESS

							Thicknesses				
Trench	Panel	Total Acreage of Panel	0-115ft Deep (Total Acreage)	115-154ft. Deep (Total Acreage)	154-178ft. Deep (Total Acreage)	Shallowest Carney is Present. (FT.)	Average Carney (FT)	Average Upper Carney(FT.)	Average Lower Carney (FT.)	Interburden between Upper and Lower Thickness (ft.)	Add to Overburden Contours
TR-1	4	72	0.8	15.1	4.6	110	16.5	NA	NA	NA	NA
TR-2	5	78	12.8	3.3	1	55	16.5	NA	NA	NA	NA
TR-2	6	103	15.75	10	11.65	50	18	NA	NA	NA	NA
TR-3	7	16	16	NA	NA	30	11.5	NA	NA	NA	NA
TR-3	8	43	25.2	7	4.4	15	15	NA	NA	NA	NA
TR-4	9	261	87.3	56.1	58.7	75	13.5	6	6.5	<2	NA
TR-4	10	210	21.6	36	34.7	60	11	6	4	<2	NA
TR-5	11A 11B	124	9.9	36.2	64.4	50	11.5 6	4.5	6	11A <2, 11B 4	11A NA, 11B 8.5
TR-5	12	123	28.8	13.6	29	35	14	4	9	<2	NA
TR-6	13	34	34	NA	NA	30	9	4	9	20	24
TR-6	14	2	NA	2	NA	140	9	4	9	36	40
TR-6	15	12	0.1	1.1	0.1	100	9	4	9	24	28
TR-7	16	131	131	NA	NA	40	8.5	5	8.5	10	15
TR-8	17	368	322.9	44.7	0.4	15	8.5	3.5	8.5	16	19.5
TR-11	18	19	19	NA	NA	10	4	2	4	11	13
TR-10	19	48	48	NA	NA	10	5	5	5	7	12
TR-9	20	22	22	NA	NA	35	4.5	3.5	4.5	9	12.5

Notes: Panels 1-3 have been eliminated from the mining plan.

Panels 4-8 are Carney seam,Panels 9 and 10 have the Carney and where it splits into Upper and Lower Carney, and Panels 11-20 are Upper and Lower Carney.
Panels 11 and 12 are primarily under 2ft difference, 11B is 4ft. Average difference.
For Panels 13-18 an average thickness of the interburden was used for these to determine the overburden depth.
For Panels 19 and 20 the borehole drilled in that area was used for the interval information.
Where coal seam splits are less than 2ft. both the upper and lower veins are considered mined with a 1ft. Thick split considered between the veins.

TABLE 3 ESTIMATED NUMBER OF SINKHOLES FOR PANELS 5 AND 6 FOR AVERAGE CARNEY THICKNESS

Panel Depth Range (ft)	Ratio of Depth to Thickness	Panel 5 Surface Area (Acres)	Panel 6 Surface Area (Acres)	Total Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<44	2.7	0.0	0.0	0.0	17.01	0.0
44-87	4.1	4.7	8.9	13.6	8.05	109.1
87-131	6.9	2.1	10.8	12.9	5.47	70.4
131-175	9.6	31.2	14.4	45.5	0.24	10.9
175-218	12.4	14.6	17.2	31.8	0.26	8.3
218-262	14.6	7.5	25.6	33.0	0.06	2.0
262-306	17.9	0.0	0.0	0.0	0.00	0.0
					Total	201

Notes:
1) TR-2 encompasses Panels 5 and 6 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 16ft.

TABLE 4 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 7 FOR AVERAGE CARNEY THICKNESS

Panel Depth Range (ft)	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<32	2.7	0.0	17.01	0.0
32-63	4.1	3.7	8.05	29.9
63-95	6.9	7.1	5.47	38.7
95-126	9.6	2.3	0.24	0.6
126-158	12.4	0.0	0.26	0.0
158-190	14.6	0.0	0.06	0.0
190-221	17.9	0.0	0.00	0.0
			Total	70

Notes:
1) TR-3 encompasses Panel 7 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 11.5ft.

TABLE 5 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 8 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<41	2.7	5.7	17.01	96.6
41-82	4.1	8.0	8.05	64.4
82-124	6.9	7.6	5.47	41.4
124-165	9.6	7.2	0.24	1.7
165-206	12.4	5.5	0.26	1.4
206-247	14.6	1.9	0.06	0.1
247-288	17.9	0.0	0.00	0.0
			Total	206

Notes:
1) TR-3 encompasses Panel 8 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 15ft.

TABLE 6 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 9 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<37	2.7	0.0	17.01	0.0
37-74	4.1	0.0	8.05	0.0
74-111	6.9	73.5	5.47	402.0
111-148	9.6	83.7	0.24	20.1
148-185	12.4	74.5	0.26	19.4
185-223	14.6	28.4	0.06	1.7
223-260	17.9	0.0	0.00	0.0
			Total	444

Notes:
1) TR-4 encompasses Panel 9 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 13.5ft.

TABLE 7 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 10 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<30	2.7	0.0	17.01	0.0
30-60	4.1	1.2	8.05	9.4
60-91	6.9	10.8	5.47	59.3
91-121	9.6	12.0	0.24	2.9
121-151	12.4	42.8	0.26	11.1
151-181	14.6	52.5	0.06	3.2
181-212	17.9	41.1	0.00	0.0
			Total	86

Notes:
1) TR-4 encompasses Panel 10 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 13.5ft.

TABLE 8 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 11A FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<32	2.7	0.0	17.01	0.0
32-63	4.1	0.0	8.05	0.0
63-95	6.9	2.3	5.47	12.6
95-126	9.6	9.0	0.24	2.1
126-158	12.4	14.2	0.26	3.7
158-190	14.6	38.0	0.06	2.3
190-221	17.9	0.0	0.00	0.0
			Total	21

Notes:
1) TR-5 encompasses Panel 11A based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 11.5ft.

TABLE 9 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 11B FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<16	2.7	0.0	17.01	0.0
16-33	4.1	0.0	8.05	0.0
33-49	6.9	0.0	5.47	0.0
49-66	9.6	1.4	0.24	0.3
66-82	12.4	0.8	0.26	0.2
82-99	14.6	0.9	0.06	0.1
99-115	17.9	1.1	0.00	0.0
			Total	1

Notes:
1) TR-5 encompasses Panel 11B based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 6ft.

TABLE 10 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 12 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<38	2.7	0.0	17.01	0.0
38-77	4.1	6.4	8.05	51.1
77-115	6.9	16.0	5.47	87.8
115-154	9.6	26.0	0.24	6.2
154-192	12.4	18.9	0.26	4.9
192-231	14.6	5.8	0.06	0.3
231-269	17.9	0.0	0.00	0.0
			Total	151

Notes:
1) TR-5 encompasses Panel 12 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 14 ft.

TABLE 11 ESTIMATED NUMBER OF SINKHOLES FOR PANELS 13, 14 AND 15 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Panel 13 Surface Area (Acres)	Panel 14 Surface Area (Acres)	Panel 15 Surface Area (Acres)	Total Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<25	2.7	0.0	0.0	0.0	0.0	17.01	0.0
25-49	4.1	0.2	0.0	0.0	0.2	8.05	1.8
49-74	6.9	2.0	0.0	0.0	2.0	5.47	11.1
74-99	9.6	6.1	0.0	0.0	6.1	0.24	1.5
99-124	12.4	2.4	0.0	0.0	2.4	0.26	0.6
124-148	14.6	0.7	0.0	4.2	4.8	0.06	0.3
148-173	17.9	0.0	0.1	3.2	3.3	0.00	0.0
						Total	16

Notes:
1) TR-6 encompasses Panels 13, 14 and 15 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 9 ft.

TABLE 12 ESTIMATED NUMBER OF SINKHOLES FOR PANELS 16 AND 17 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Panel 16 Surface Area (Acres)	Panel 17 Surface Area (Acres)	Total Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<23	2.7	0.0	0.0	0.0	17.01	0.0
23-46	4.1	2.5	58.4	60.9	8.05	489.9
46-70	6.9	79.6	58.4	138.0	5.47	755.0
70-93	9.6	37.4	59.6	97.0	0.24	23.3
93-117	12.4	11.5	79.8	91.2	0.26	23.7
117-140	14.6	0.0	61.9	61.9	0.06	3.7
140-163	17.9	0.0	29.7	29.7	0.00	0.0
					Total	1296

Notes:

1) TR-7 and TR-8 encompass Panels 16 and 17, respectively based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 8.5 ft.

TABLE 13 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 18 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<11	2.7	0.0	17.01	0.0
11-22	4.1	0.0	8.05	0.0
22-33	6.9	0.0	5.47	0.0
33-44	9.6	9.7	0.24	2.3
44-55	12.4	9.4	0.26	2.4
55-66	14.6	0.0	0.06	0.0
66-77	17.9	0.0	0.00	0.0
			Total	5

Notes:
1) TR-11 encompasses Panel 18 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 4 ft.

TABLE 14 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 19 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<14	2.7	0.0	17.01	0.0
14-27	4.1	0.0	8.05	0.0
27-41	6.9	23.2	5.47	127.0
41-55	9.6	9.3	0.24	2.2
55-69	12.4	11.8	0.26	3.1
69-82	14.6	3.6	0.06	0.2
82-96	17.9	0.0	0.00	0.0
			Total	133

Notes:
1) TR-10 encompasses Panel 19 based on MEA Figure 4.3
2) Overburden contours used are found on Addendum D5-4 Exhibit 1
3) Assumed Coal Height of 5ft.

TABLE 15 ESTIMATED NUMBER OF SINKHOLES FOR PANEL 20 FOR AVERAGE CARNEY THICKNESS

Ratio of Depth to Thickness	Ratio of Depth to Thickness	Surface Area (Acres)	Density of Subsidence Features (No./Acre)	No. of Subsidence Features
<12	2.7	0.0	17.01	0.0
12-25	4.1	0.0	8.05	0.0
25-37	6.9	5.6	5.47	30.9
37-49	9.6	3.5	0.24	0.8
49-62	12.4	6.6	0.26	1.7
62-74	14.6	3.3	0.06	0.2
74-87	17.9	2.6	0.00	0.0
			Total	34

Notes:

1) TR-9 encompasses Panel 20 based on MEA Figure 4.3

2) Overburden contours used are found on Addendum D5-4 Exhibit 1

3) Assumed Coal Height of 4.5ft.

ATTACHMENT A

Documents Reviewed

Response to EQC Finding of Facts and Conclusions of Law, WDEQ Comments Round 7 – Brook Mine Permit to Mine Application TFN 6 2/025

Figure 2.3-1 – Carney Seam Pre-mine Potentiometry (Round 7 and Round 9)

Addendum MP-6 – Subsidence Control Plan (Round 7 and Round 9)

Addendum MP-6-11 (Round 8 and Round 9)

Addendum MP-6-12,13,14,15 (Round 7 and Round 9)

Attachment MP-6-A (Round 9)

Mining Plan (Round 8 and Round 9)

Table MP.1-3,4 (Round 7 and Round 9)

Figure MP.1-1,2,3,4,5 (Round 7 and Round 9)(MP.1-5 Removed in Round 9)

Figure MP.4-1,2,3 (Round 7 and Round 9)

Figure MP.2-1,2 (Round 9)

Figure MP.3-1 (Round 9)

Figure MP.9-1 (Round 7 and Round 9)

Mine Plan Exhibits (Round 8 and Round 9)

Index Sheet for Mine Permit Amendments or Revisions (Round 8 and Round 9)

Mining Plan Table of Contents (Round 8 and Round 9)

Exhibit MP.15-1,2 (Round 7 and Round 9)

Brook Mine_New Permit Application_CHIA 39_DRAFT_28Feb2020 (Round 12)

Reclamation Plan (Round 9)

Appendix D5 Topography, Geology and Overburden Assessment (Round 9)

Appendix D6 Hydrology (Round 7 and Round 9)

Addendum MP3 Hydrostatic Units (Round 7 and Round 9)

Brook RD10_Total Submittal_Combined (Round 10)

RAMACO_CARF_2019_GW_Elevations (Round 10)

RAMACO_CARF_2019_GW_Quality_Field (Round 10)

RAMACO_CARF_2019_GW_Quality_Lab (Round 10)

Round 8 Technical Review, DEQ Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 8 Technical Review, Ramaco Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 9 Technical Review, DEQ Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 9 Technical Review, Ramaco Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 10 Technical Review, DEQ Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 10 Technical Review, Ramaco Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 11 Technical Review, DEQ Comments/Cover letter, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 12 Technical Review, DEQ Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 12 Technical Review, Ramaco Comments, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 12 Technical Review, Ramaco Cover Letter, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 12 Technical Review, Ramaco Submittal, Brook Mine Coal Mine Permit Application, TFN 6 6/025

Round 12 Technical Review, Ramaco Comments Change Index, Brook Mine Coal Mine Permit Application, TFN 6 6/025

ATTACHMENT B

MEA January 23, 2017 Report

January 23, 2017

Ms. Shannon Anderson
Acting Director
Powder River Basin Resource Council
934 Main St.
Sheridan, WY 82801

Re: Brook Mine Permit Application

Ms. Anderson,

As you have requested, I have reviewed the mine application for the proposed Brook Mine by Ramaco, LLC. This proposed mining is located about 8.5 miles north of Sheridan, WY (see Figure 1.1). In my evaluation of the Ramaco mine application, I performed a cursory to detailed review of the following documents:

- Mine Plan
  - Addendum MP-1: Alternative Sediment Control Measures
  - Addendum MP-3: Groundwater Model
  - Addendum MP-6: Subsidence Control Plan
  - Addendum MP-7: Blasting Plan Supplemental Materials
- Appendix D2: History
- Appendix D5: Topography, Geology, and Overburden Assessment (Oct. 2014 and Jul. 2015)
  - Addendum D5-1: Drill Hole Tabulations (State Plane Coordinates)
  - Addendum D5-2: Lithologic and Geophysical Logs

    - Addendum D5-3: Geologic Cross-Sections
    - Addendum D5-4: Isopach Maps
    - Addendum D5-5: Overburden, Roof and Floor Sample Analysis Tables
    - Addendum D5-6: WDEQ/LQD Overburden Sampling Frequency Waiver
    - Addendum D5-7: Soil Analysis Reports
- Appendix D6: Hydrology
    - Addendum D6-1: HEC-HMS Model
    - Addendum D6-2: Miller Regression Analysis
    - Addendum D6-3: HEC-RAS Model
    - Addendum D6-4: Surface Water Hydrographs
    - Addendum D6-7: Monitor Well Completion Data
    - Addendum D6-8: Pumping Test Report
- Appendix D11: Alluvial Valley Floors
- Bond Estimate
- Reclamation Plan
- Effects of Coal Mine Subsidence in the Sheridan, Wyoming Area, USGS Paper 1164 by C. Dunrud and F. Osterwald, 1980
- Technical Report on the Welch Ranch Coal Fire by E. Heffern, J. Queen, and K. Henke, April 28, 2003
- 2014-2019 Sheridan County, WY Multi-Hazard Mitigation Plan
- USDA Soil Survey of Sheridan County Area, Wyoming

SITE TOPOGRAPHY

The topography of the mine site is shown in Figure 1.2. As seen in Figure 1.2, except for the southeastern “leg” of the application area, the proposed mine site is just north of the meandering east-west Tongue River, with the overall ground surface within this application area draining to the Tongue River. The main drainage features trend NW-SE (e.g. Early Creek, E. Fork Early Creek, Slate Creek, and Hidden Water Creek) approximately conjugate to known fault traces. Between each tributary or drainage incision, the surface elevations reach about 3,840 ft. – 4,100 ft., with relief from the valley of typically 150 ft. to 200 ft. The lowest point is shown at about 1,680 ft. El. at the Tongue River whereas the highest point depicted is centrally located near the north limits of the application area at Elevation about 4,100 ft. In the smaller southeastern “leg” of the application area, the ground basically drains west into Goose Creek or to the north into the Tongue River.

GEOLOGIC CONDITIONS

Within the mine application area, the relevant geologic materials are reported to be weathered to unweathered rock and colluvium from mass wasting. These rock beds belong to the Union Fort Formation of Tertiary age with the coal bearing strata in the lower sequences of the Tongue River Member. See Figure 2.1. Below the Tongue River Member is the Lebo Member which regionally consists of mainly clayey shale.

Mineable heights of the site sub-bituminous coal beds are discontinuous across the site. The main seams that will be mined are the Carney and the lower Masters. The Carney seam splits to the west into the upper and lower Carney benches. This claystone parting is reported to reach a thickness in excess of 30 ft. Where the Carney is vertically continuous, it is stated to be 15 to 20 ft. thick, but when it splits, the upper unit is 2 to 6 ft. thick, and the lower, which typically has better quality, is 4 to 10 ft. thick. The thickness of the underlying Masters, where present, was found to be 4 to 6 ft.

There is also the potential that the overlying Monarch and other more localized coal beds will be mined. It is noted that much of the Monarch seam has been burnt into scoria.

The interburden thickness between the Carney and the Masters has been measured to be from less than 1 ft. at the eastern mine application limit to over 50 ft. As described in the mine application, the vast majority of the coal measures are composed of claystone with fairly localized layers of moderately to well cemented sandstone to siltstone lenses. In other words, the floor of the mineable coal seams is claystone. The Lebo member which underlies the Master Coal measures is described as mudstone.

The application area is known to be faulted. Normal faults are reported which trend NE-SW causing a horst and graben structure across the mine area, the dip of this faulting, or the character of it's broken zone are not known. Based on the surface drainage features conjugate structure may also be present. The dip of the beds in the faulted blocks is reported to be about 2 degrees in the south-southeast direction.

GEOTECHNICAL CONDITIONS

From review of the relevant portions of the permit application, all the reported geotechnical laboratory results for the coal measures in the reserve are summarized in Table 3.1. As can be seen here, there has been scant few rock mechanics testing. And consequently no sense of the important engineering properties and their spatial variations of the relevant coal measures through the reserve can be realistically achieved. The rock mechanics testing should include:

- Moisture content
- Liquid and plastic limits determinations
- Rock durability
- Tensile strength
- Uniaxial compression or Point load strengths
- **Consolidated-drained** triaxial strength
- Swell potential

Furthermore, from a geotechnical engineering standpoint, the rock descriptions for the borings drilled are wholly inadequate. This includes:

- No RQD measurements
- No fracture descriptions – are fissures or slickensides present and at what frequency?
- No to inadequate (uncodified) hardness descriptions
- No codified description of rock classifications

From a geotechnical engineering perspective, there is a severe concern given that the vast majority of the coal measures are described as claystone. Claystone represents very poor mine roof and floor conditions in addition to highwall stability problems. Fine-grained rocks are likely to significantly reduce in strength over time as they swell/soften and deteriorate (Marino and Osouli, 2012). Also, there appears to be mischaracterization as some of the reported claystone as it is described to be fissile, which indicates bedding (not a non-bedded rock).

To properly understand the engineering material nature of fine-grained rocks, sufficient testing of the rock plasticity (Atterberg Limits) and rock durability should be performed (Marino and Osouli, 2012).

MINE PLAN

Ramaco plans to mine with the reserve area mainly in two coal seams. They are the Carney and Masters coals. In the western part of the reserve, the Carney coal seam splits into upper and lower beds. Because these mineable beds are covered, Ramaco plans to create highwalls to expose them by excavating mainly slots or areas by strip mining. Once the mineable seam(s) are exposed, they will be extracted utilizing a remote-controlled continuous miner and conveyor system. An illustration of this proposed highwall operation was provided by Ramaco in Figure 4.1.

The plan showing the areas of proposed mining are depicted in Figure 4.2. This plan shows the blocks of highwall mining and associated strip mining areas. In Figure 4.3, the delineated coal blocks have been numbered for future reference from 1 to 20 east to west. As noted in the application, Ramaco plans to mine essentially from east to west.

The coal blocks will be mined from benches along the highwall by driving parallel entries into the highwall face apparently perpendicular to the highwall. A remote continuous miner system will be utilized to drive the rooms to depths of up to 2,000 ft. The mining equipment that will be used is an ADDCAR highwall mining system with accuracy of 0.1m in 384m of penetration. However, potentially more significant in determining the actually cut pillar widths is the azimuth accuracy which is not discussed. Using this continuous miner, it is noted that typical extraction heights of 30 in. to 28 ft. can be achieved.

The proposed room and pillar configuration is depicted in Figure 4.4. As can be seen in Figure 4.4, there is no definitive geometry stipulated in the application as much of the identified dimensions are qualified. Using the “typical” web pillar widths and room width, the panel extraction ratio would vary from 59% to 70% in the panels.

Ramaco also states that where multiple coal seams will be mined in a block the pillars will be stacked. With apparently the parallel entries of about the same width, this means the pillar width would be the same for all seams of different thickness. Ramaco states the pillar width will be determined by the seam with the greater thicknesses [MP-6-7].

In order to better understand the ground conditions in the areas of proposed mining, the mining layout given in Figure 4.3 has been superimposed over the various isopach exhibits for the Carney and Masters seams provided in the mine application. These drawings are shown in Figures 4.5 to 4.12. Also, the mine block areas had been delineated on the various geologic cross-sections drawn by Ramaco across the site (see Figure 4.3). The modified cross-sections showing the mine block locations are shown in Figures 4.13 to 4.24. From this reported information, the Dietz, Monarch, Carney, and Masters related conditions per block have been summarized in Table 4.1.

Other considerations are noted below.

- There is no discussion that could be found on reclamation of the mine openings in the highwalls which are left after an area is complete. Depending upon the seal (if any) and dip of the coal, groundwater (and runoff if not sealed) can pool in the entry. Also, if any of these areas are contoured, these entries, as a source of water, can have a detrimental effect of the stability of the reclaimed slope.

- The mine application notes oil and gas wells are present. There is no discussion that could be found on how these wells will be addressed during mining, or how they will be handled if the well is mislocated or was unknown when encountered during mining.

- Ramaco has not addressed the potential for the significant portion of the pillar being composed of claystone from mining in the blind where the coal has significantly variable thickness, or clay parting(s).

MINE STABILITY ANALYSIS

An integral part of assessing the subsidence potential for any proposed coal mining is the determination of whether the coal mine structure will be stable in the short and long term. The mine application, however, provides no calculations of the planned and expected roof, pillar, or floor conditions. In fact, the only governing criteria provided is that "support pillars will be designed to have a width equal to or exceeding the maximum extraction thickness" [MP-6-4]. Ramaco states that this is based on the NIOSH pillar stability program and the recommended stability factor (i.e. safety factor) and that "pillar dimension will also be in accordance with Brook Mine's Ground Control Plan approved by MSHA". Contact with MSHA found that no ground control plan has been filed. They stated that such a plan applies to open pit conditions and thus would not address pillar dimensions (although the NIOSH pillar program manual for highwall mining notes it is part of the MSHA ground control plan). Moreover, approval from MSHA (whose responsibility is safety) is irrelevant as the concern here is land subsidence.

In stating the pillar width to height ratio will be one or greater, none of the input assumptions or output for the pillar dimension criteria have been provided to evaluate how this criterion was arrived at. For example, the assumed coal strength for the various subbituminous seams (without any substantial test data), assumed coal extraction, and the assumed overburden depth are not known. Also, there is no discussion in the mine application of the effect of multiple seam mining (including overlying or subjacent old works presence) [NISOH ARMPS-HWM]. Moreover, the proposed utilization by Ramaco of the coal tensile strength to assess pillar strength is not standardly done in the industry [D5-10].

There is no governing roof and floor design criteria on what will dictate the barrier and web pillar width and spacing, and panel width to avoid complete overburden instability, based on the variable ground/mining conditions which may be encountered (see Figure 5.1). This is especially problematic given the reported very poor roof and floor consisting mostly of claystone although resistance augmented siltstone and sandstone zones exist there locally (see Figure 4.13 to 4.24).

With the poor identification of the following conditions, it is impossible to obtain a reasonable understanding of the short and long term stability of the proposed mining (or even the slope/highwall). This includes:

- More definitive room-and-pillar layout.

- Sufficient understanding of the engineering properties of the roof, pillar, and floor materials.

- Sufficient understanding of the geologic structure including the nature and orientation (strike and drip) of all faults and shears; and fissure/slickenside concentrations.

An idea of the mine stability conditions can be obtained, however, from the available information. From Table 4.1, mine depths of over 400 ft. are planned with extraction heights reaching 18+ ft. Given the mine depths and planned panel extraction ratios, tributary pillar pressures up to close to 1,300 psi will exist. Even assuming a higher bituminous coal strength at pillar width to heights of one (as proposed), the stability factor calculates to an unacceptable value of less than one at this pillar pressure where the panels are sufficiently wide.[1] This was calculated using the Mark-Bieniawski pillar strength equation, which is the same one used by Ramaco and cited by MSHA. Also, this pillar bearing load will be well in excess of the reported claystone roof and floor (Marino and Bauer, 1989).

Other concerns which have not been addressed but can play a role in the stability of the proposed mine workings include:

- The effect of flooding or pooling of groundwater. Saturation or repeated cycles of wet and dry of the clay roof, pillar (partings) and floor can dramatically effect it's inplace strength, and subsequently causing failure. Inflows of groundwater are

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[1] Note the MSHA criteria for pillar strength were based on pillar heights of 7 ft. or less whereas 18 ft. heights are proposed.

noted by Ramaco from drainage and where aquifers are saturated [MP-45]. Although a 500 ft. coal barrier is planned between the old works and the Brook Mine [MP67-8], there is also the potential that the proposed mining can be inundated from the presence of adjacent old Carney workings that may contain water. This risk is attributed to unmapped workings and unknown geologic structures. Note on Figure MP-6.1-1, the old works are not shown buffered with barrier pillars 500 ft. in width. Moreover, the drainage of pool or flooded old workings can reactivate or cause additional land subsidence in those areas.

- Effect of stacking of pillars on stability with change in interburden thickness; and the accumulated void height and the effect on chimney subsidence.

- As noted in the permit application, a clay parting cuts the Carney seam into upper and lower benches. There is not discussion or analysis of when the parting becomes sufficiently thick to cause pillar instability and consequently resort to mining the upper or lower bench. How the remote continuous miner “blindly” cuts just coal is not discussed.

Although not a mine subsidence concern, there can be serious slope/highwall instability given the extent of claystone throughout the reserve in addition to the evidence of faulting. The proposed benches for support of mining equipment and personnel are also similarly subjected to instability, especially since these claystone areas will tend to collect slope runoff and minewater.

SUBSIDENCE POTENTIAL

The subsidence of the proposed Brook Mine is discussed in the Subsidence Control Plan of the mine application. Subsidence can basically come in the form of pits (sinkholes) and sags. Pits form on the ground surface from the complete collapse of the overburden into a mine entry. Sags are mine subsidence events which are bowl-shaped depressions. They are caused by overburden collapse in the mine entry, a pillar failure, and a bearing failure in the roof or floor. Entry-induced sag events tend to be significantly smaller than those from a pillar or bearing failure. (See MEA Engineering UPDATE Issue 14).

The pit subsidence over the old workings in the mine application area can be seen in the aerial photographs as shown in Figure 7.1 to 7.5. These photographs show areas of more isolated to intense patterns of pit subsidence indicating poor overburden roof conditions. This is consistent with the vast majority of the rock overburden described as claystone without resistant durable interbeds. There also appears to be some subsidence-induced slop instability (i.e. slump features in Area 2, Figure 7.2). The mine depth is estimated to reach up to 160 ft. in visible subsidence areas. Broader subsidence events (i.e. sags) from pillar or pillar bearing failure or mine fire are not noticeable on aerials photographs examined but also are reported in the region.

Ramaco's subsidence analysis treats entry-induced subsidence (i.e. chimney subsidence) by analyzing pit subsidence over the historic Mine No. 44 by utilizing a roof stoping equation by Dyne, 1998 for a four-way equal width room intersection which is provided below.

$$z = 12/ (\pi\ (k-1)\ (d_{base}^2 + d_{surf}^2 + d_{base}d_{surf}))\ (\pi/12t\ (d_{base}^2 + D^2 + Dd_{base}) - ((D-w)\ /6 \tan\theta)\ (D^2 \arccos (w/D) = D^2/2 \sin (2\arccos (w/D)) - \pi\ D^2/4 + w^2))$$

The equation is based on the following variables:

- w = width of mine rooms (ft.)
- t = height of seam (ft.)
- k = bulking factor = V_B/V where V is the initial volume and $V_{\mathbf{B}}$ is the volume of rubble
- θ = angle of repose of caved rock within mine room
- d_{base} = diameter of collapse-chimney at base (ft.)
- d_{surf} = diameter of collapse-chimney at surface (ft.)
- D = diameter of caved rock foot print on mine room floor (ft.)

Ramaco "confirms" that with use of the above relationship that this relationship is representative of the observations of pit subsidence to a depth of 150 ft.[2] by assuming certain parameter values. Ramaco does not, however, use this same stoping relationship which was 'confirmed' based on historic pit subsidence to actually assess

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[2] Using assumed parameter values by Ramaco, z calculates to 124 ft. and 145 ft. for chimney diameters/roof spans of 25 ft. and 20 ft., respectively.

the stoping potential of the proposed mining. It is only stated that the “proposed highwall mining opening widths of 11 to 11.5 ft. are significantly less than” the historic Mine No. 44 [MP-6-7]. When assuming the above chimney subsidence relationship, with intersecting entries were assumed at 11-11.5 ft., as proposed, and considering the same Ramaco assumed parameter values, z (or the stoping depth) becomes 219-227 ft. However, assuming a four-way equal room width intersection, as in the above stoping equation, does not represent any of the actual pit locations as indicated by the mine map.

Considering pit subsidence along entries without intersections, which is more representative of the underlying historic subsidence conditions, and assuming a repose angle of slaked claystone cavein of 20° and the other Ramaco assumptions, a bulk factor of 1.33 is calculated. Under the proposed mining conditions and considering this back-calculated bulking factor, the potential stoping height (or mine depth) becomes about 225 ft. Clearly, with the claystone overburden of limited reported resistant, durable beds, reported Carney thickness of 15-20 ft. (in lieu of the assumed thickness of 14 ft.), and greater mine depths experiencing pit subsidence reaching up to about 160 ft. (see Figures 7.1 to 7.5), there is a serious risk of surface subsidence from roof collapse in the proposed mining. Also, Ramaco does not address the proposed stacking of mine entries (i.e. pillar stacking) effect on the upward chimney propagation. Clearly the accumulated void height could produce greater exposure to land surface subsidence.

Although there is no substantial geotechnical exploration or testing or analyses that were, or could be performed - from our experience with the claystone roof and floor, the proposed mining can result in sag subsidence. Pillar failure can also result in sag subsidence. Calculations and assumptions made by Ramaco to demonstrate that short and long term failure from pillar crushing are not provided. Ramaco asserts that pillars with width to height ratios in excess of one are adequate without any substantial coal strength or clay parting data and further states that an approved MSHA-approved ground control will be obtained. This statement is “putting the cart before the horse” when this is a requirement of the subsidence control plan. Moreover, the ground control that is required by MSHA will likely not include mine stability analysis as highwall mining does not require miner ingress.

SUMMARY AND CONCLUSIONS

As requested by the Powder River Basin Resource Council, MEA has performed a subsidence engineering review of the proposed Brook Mine application submitted by Ramaco, LLC. This investigation primarily consisted of examination and evaluation of pertinent sections of the application to assess the subsidence potential of the proposed plan. The findings from this investigation are provided immediately below, however this report should be read in its entirety to obtain a complete understanding of its contents.

1. The proposed Brook Mine is located about 8.5 miles north of Sheridan, WY. The mine plans to mine primarily two sub-bituminous coal seams. These seams are the Carney and the underlying Masters. The Carney Seam is reported to split in

the western half of the application area into upper and lower beds. The clay parting between the upper and lower beds is said to reach more than 30 ft.

2. The coal will be extracted primarily by highwall mining methods. The highwalls will be created by strip mining slots or areas.

3. Based on the reported data, for the Carney, Masters, and other overlying seams, the mining depth is expected to range from near the surface to about 420 ft. with extraction heights that can range as low as 2.5 ft. and exceed 18 ft.

4. The vast majority of the associated coal measures are described as claystone with isolated interbeds of sandstone/siltstone. These coarser grained interbeds are laterally discontinuous but where present exist up to a thickness of 36 ft.

5. The proposed highwall mining is expected to result in 11-11.5 ft. wide parallel entries up to 2,000 ft. into the highwall face with panel extraction ratios of 60 to 70%. Given this range of extraction and mine depth, tributary pillar pressures up to close to 1,300 psi can be expected.

6. A detailed and advanced subsidence engineering analysis is required given the reported geologic and mining conditions. However, the mine subsidence potential investigation provided in the mine application is wholly inadequate and thus renders it impossible to perform an adequate peer review. Of most particular

concern is: 1. the lack of codified rock mass classifications, geologic structure, and geotechnical properties of the relevant coal measures; 2. essentially no short and long term mine stability analyses of all potential failure modes that can lead to surface subsidence; and 3. no appropriate examination of risk, severity, and types of potential subsidence.

7. Given the pervasive extent of claystone reported above, throughout, and below the proposed mining interval, there is serious concern for short and long term mine instability. There are a number of problematic conditions which are discussed above.

8. There is a massive amount of surface subsidence in the area at mine depths similar to that proposed. Based on the reported data, chimney subsidence analyses, and examination of historic air photos in the area, both sag and pit subsidence would be expected at the Brook Mine.

If you have any questions, please don't hesitate to contact me.

Sincerely,

Professional Engineer (Civil)
GENNARO G. MARINO
PE 12993
Date 1/23/17
WYOMING

Gennaro G. Marino, Ph.D., P.E., D.GE
President

Enclosures:

FIGURE 1.1 LOCATION OF PROPOSED MINING

FIGURE 1.2 LOCATION OF MINE APPLICATION AREA FOR THE PROPOSED BROOK MINE SUPERIMPOSED ON QUAD TOPO MAP

FIGURE 2.1 GEOLOGIC COLUMN FOR PROPOSED MINE SITE (SEE P. D5-F4)

FIGURE 4.1 ILLUSTRATION OF PROPOSED HIGHWALL MINING OF COAL VIA STRIP-MINED TRENCH EXCAVATIONS (SEE P. MP-F2)

FIGURE 4.2 PROPOSED MINE PLAN (SEE EXHIBIT MP.15-1)

FIGURE 4.3 PLANNED TRENCH AND COAL BLOCK AREAS WITH FAULTS AND CROSS SECTION LINES

FIGURE 4.4 PROPOSED HIGHWALL MINING ROOM AND PILLAR CONFIGURATION (SEE P. MP-F3)

FIGURE 4.5 CARNEY COAL SEAM OVERBURDEN ISOPACH MAP (UPPER CARNEY WEST OF CARNEY SPLIT) WITH PROPOSED MINE LAYOUT

FIGURE 4.6 CARNEY COAL SEAM THICKNESS ISOPACH EAST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

FIGURE 4.7 UPPER CARNEY COAL SEAM THICKNESS ISOPACH MAP WEST OF CARNEY SEAM SPLIT WITH PROPOSED MINE LAYOUT

FIGURE 4.8 UPPER AND LOWER CARNEY COAL SEAM INTERBURDEN ISOPACH MAP, WEST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

FIGURE 4.9 LOWER CARNEY COAL SEAM THICKNESS ISOPACH MAP, WEST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

FIGURE 4.10 CARNEY AND MASTERS COAL SEAM INTERBURDEN ISOPACH MAP WITH PROPOSED MINE LAYOUT

FIGURE 4.11 MASTERS COAL THICKNESS ISOPACH WITH PROPOSED MINE LAYOUT

FIGURE 4.12 MASTERS COAL BOTTOM ELEVATION ISOPACH WITH PROPOSED MINE LAYOUT

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Dyne, L.A., 1998. The Prediction and Occurrence of Chimney Subsidence in Southwestern Pennsylvania. Virginia Polytechnic Institute and State University, January, 1998.

Marino, G. G., and Bauer, R. A., 1989, Behavior of Abandoned Room and Pillar Mines in Illinois, Int'l Journal of Mining and Geological Engineering, 11 pp.

Marino, G. G. and Osouli, A., 2012, The Influence of Softening on the Mine Floor Bearing Capacity: A Case History. Journal of Geotechnical and Geoenvironmental Engineering. In-Press.

FIGURE 1.1 LOCATION OF PROPOSED MINING

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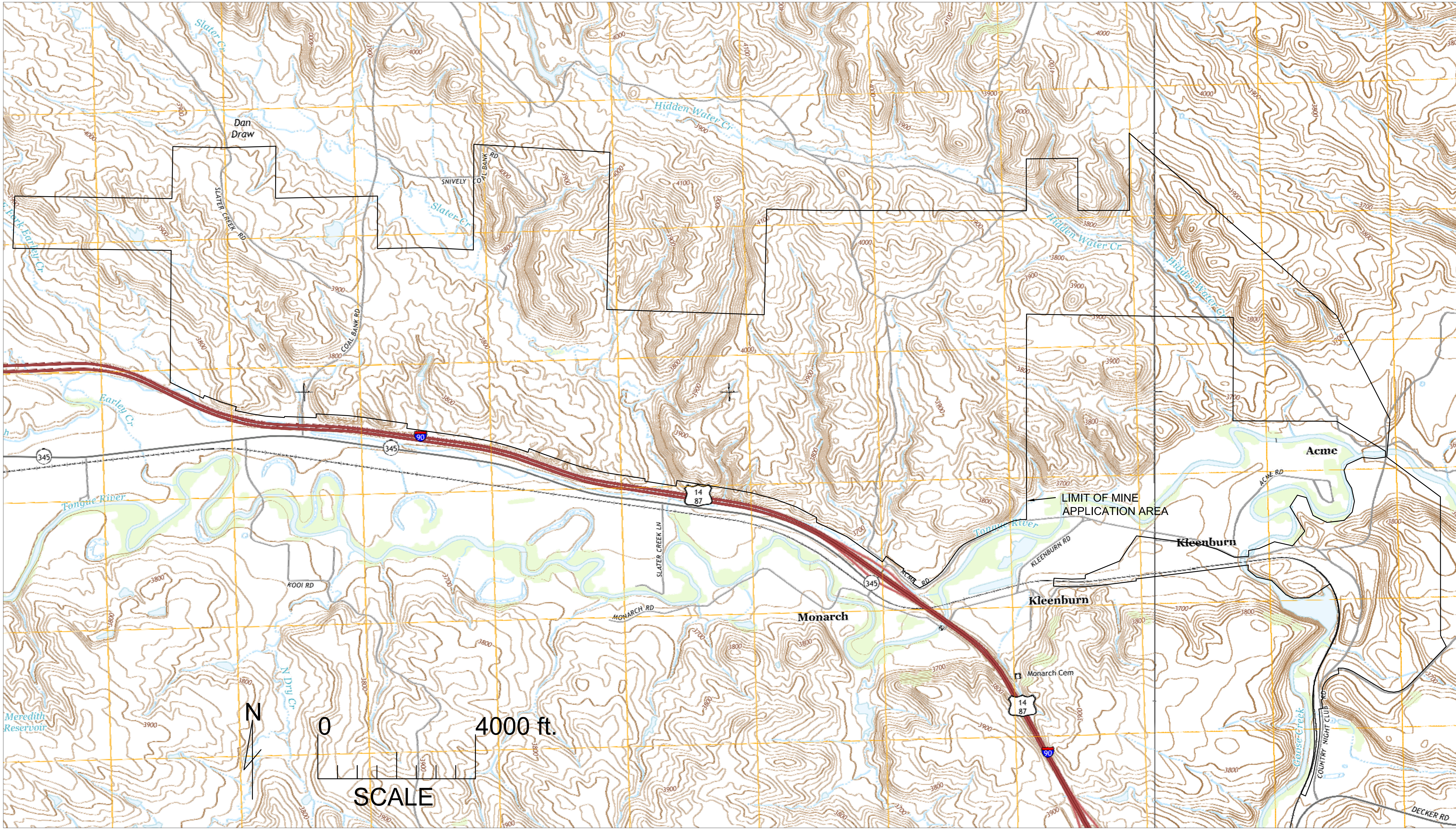

FIGURE 1.2 LOCATION OF MINE APPLICATION AREA FOR THE PROPOSED BROOK MINE SUPERIMPOSED ON QUAD TOPO MAP

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Carney lies above the Masters and "generally mark the bottom of the Tongue River Member" p. D5-10

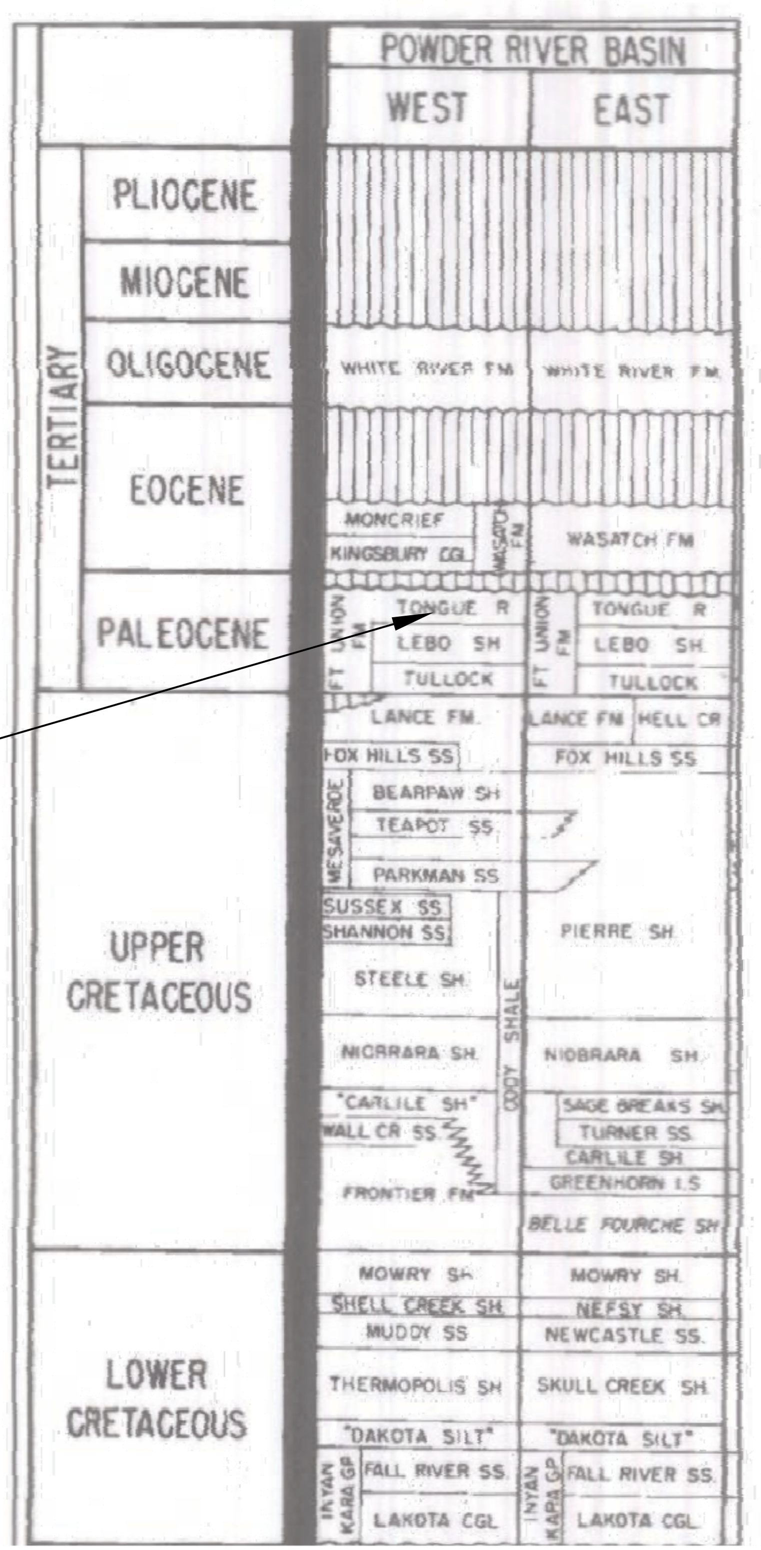

FIGURE 2.1 GEOLOGIC COLUMN FOR PROPOSED MINE SITE (SEE P.D5-F4)

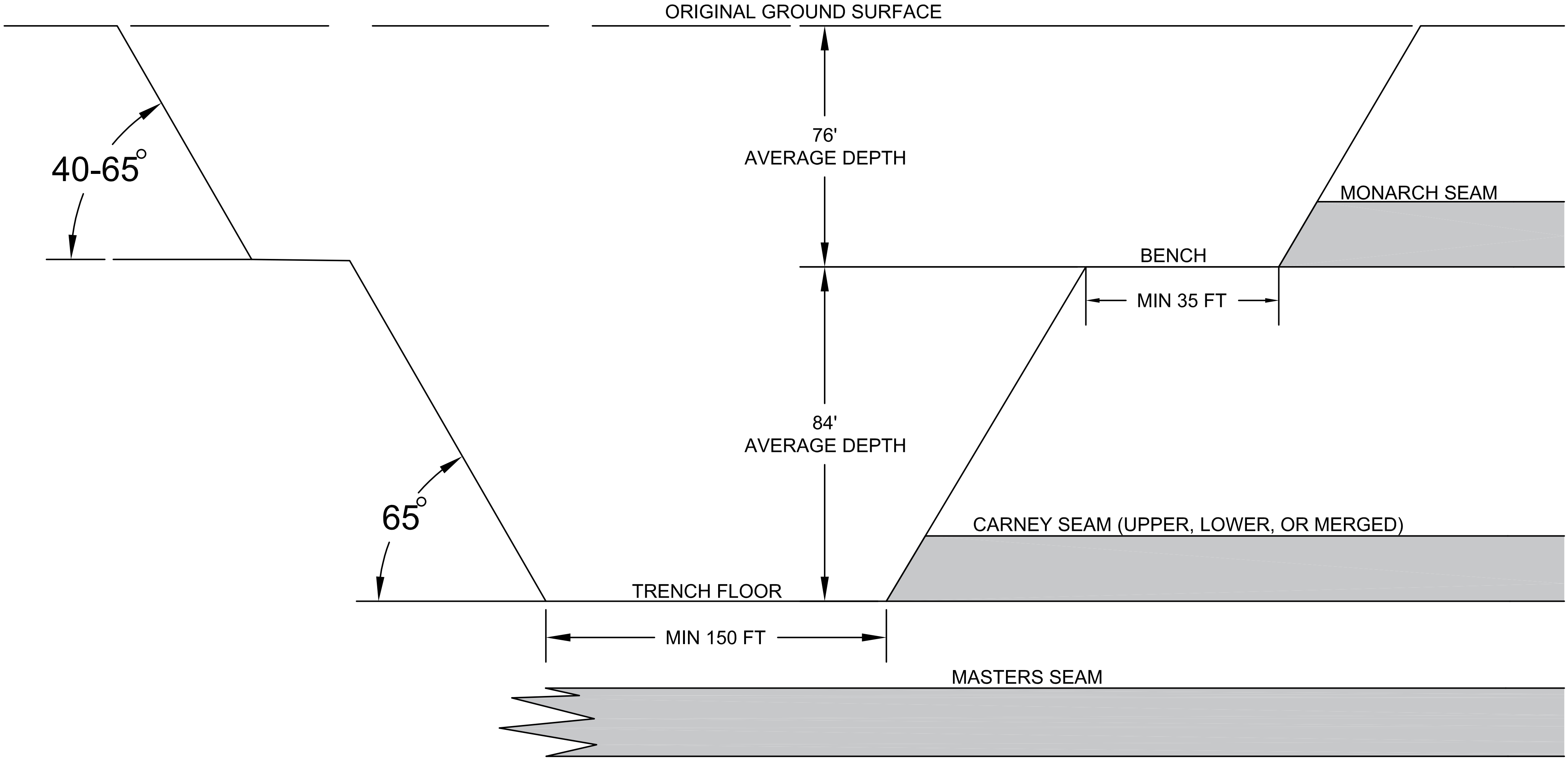

FIGURE 4.1 ILLUSTRATION OF PROPOSED HIGHWALL MINING OF COAL VIA STRIP-MINED TRENCH EXCAVATIONS (SEE P. MP-F2)

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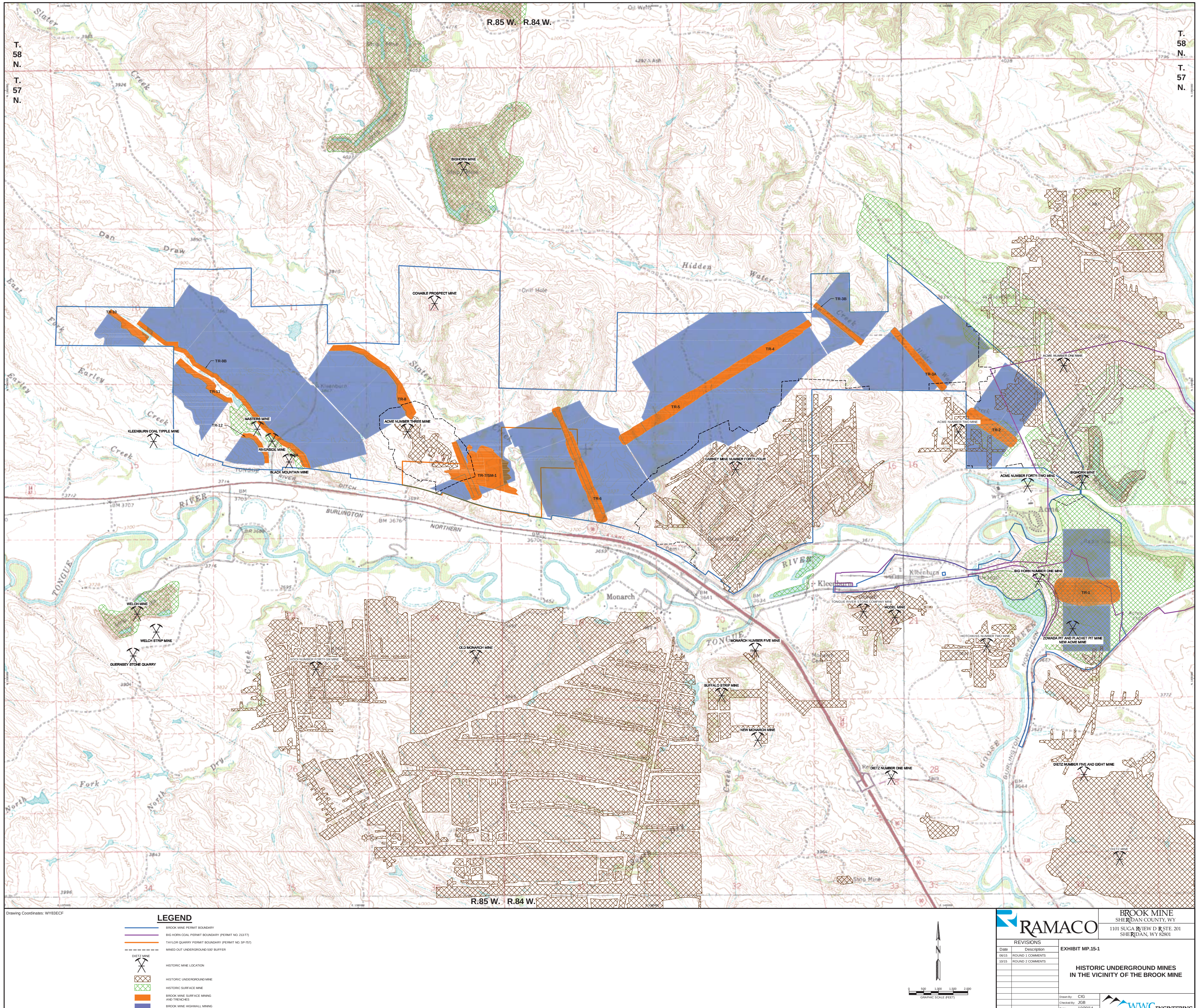


FIGURE 4.2 PROPOSED MINE PLAN (SEE EXHIBIT MP.15-1)

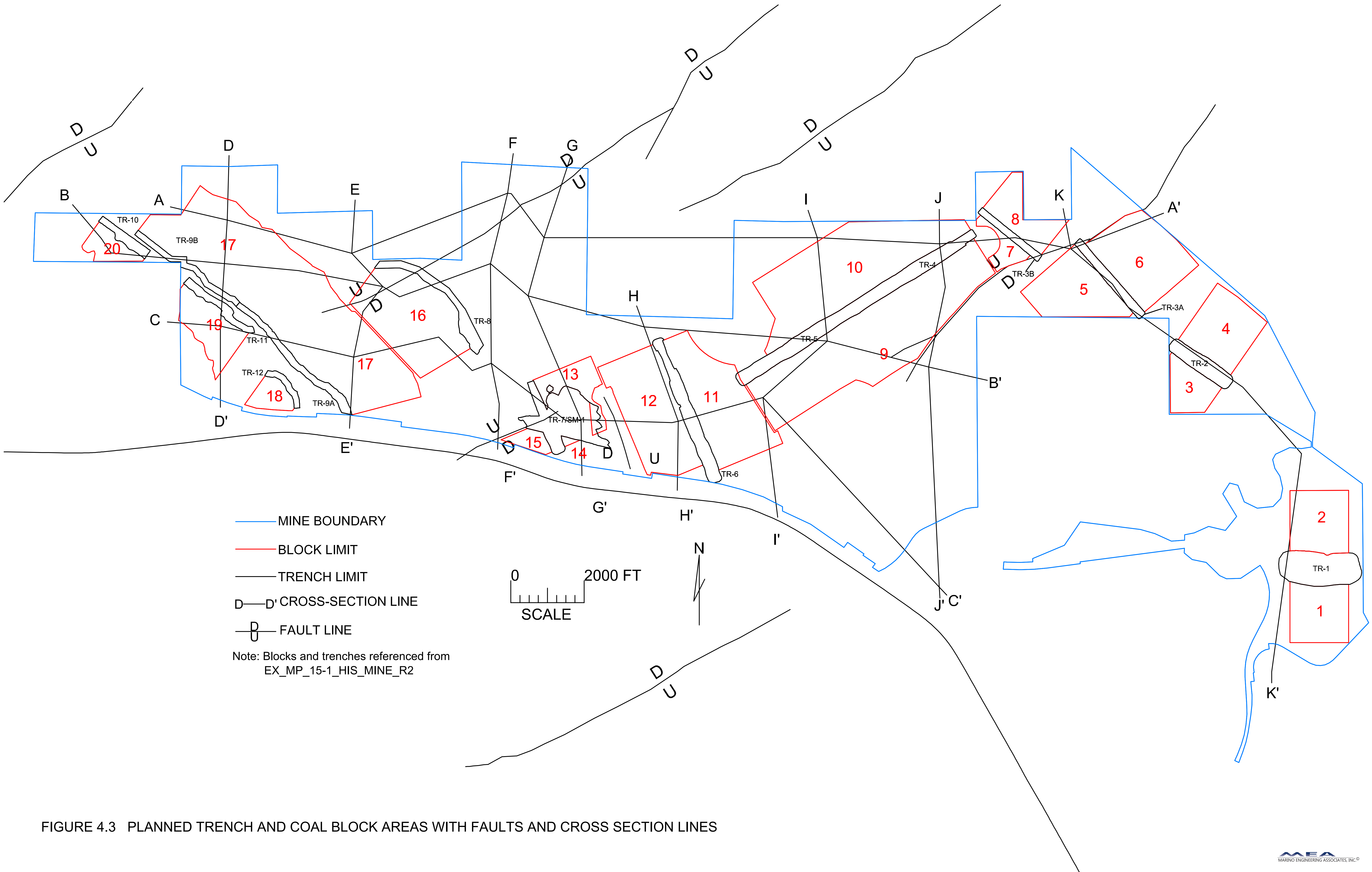
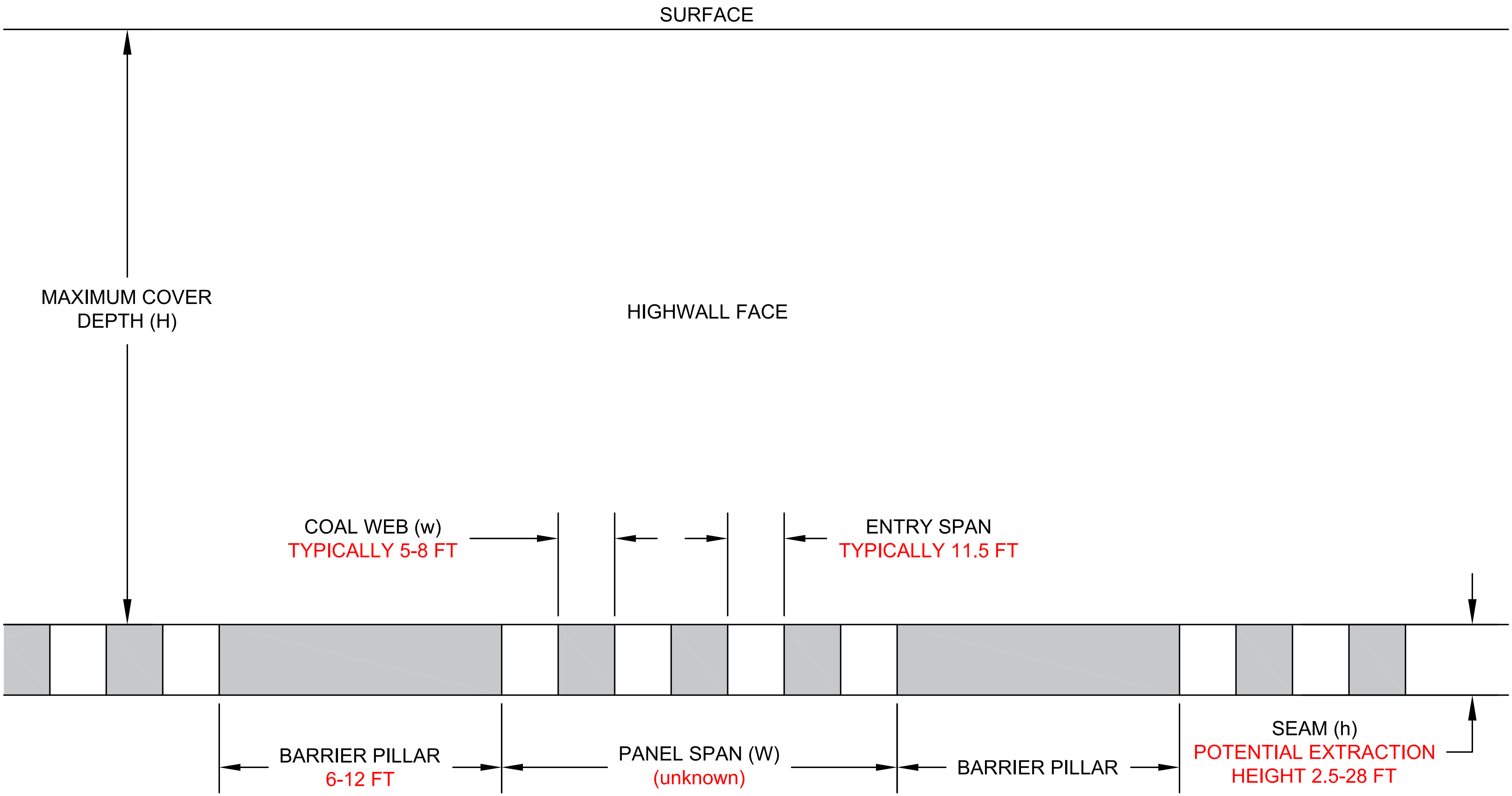


FIGURE 4.3 PLANNED TRENCH AND COAL BLOCK AREAS WITH FAULTS AND CROSS SECTION LINES



NOMENCLATURE FOR GUIDELINES - HIGHWALL MINING

NOT TO SCALE

FIGURE 4.4 PROPOSED HIGHWALL MINING AND PILLAR CONFIGURATION (SEE P. MP-F3)

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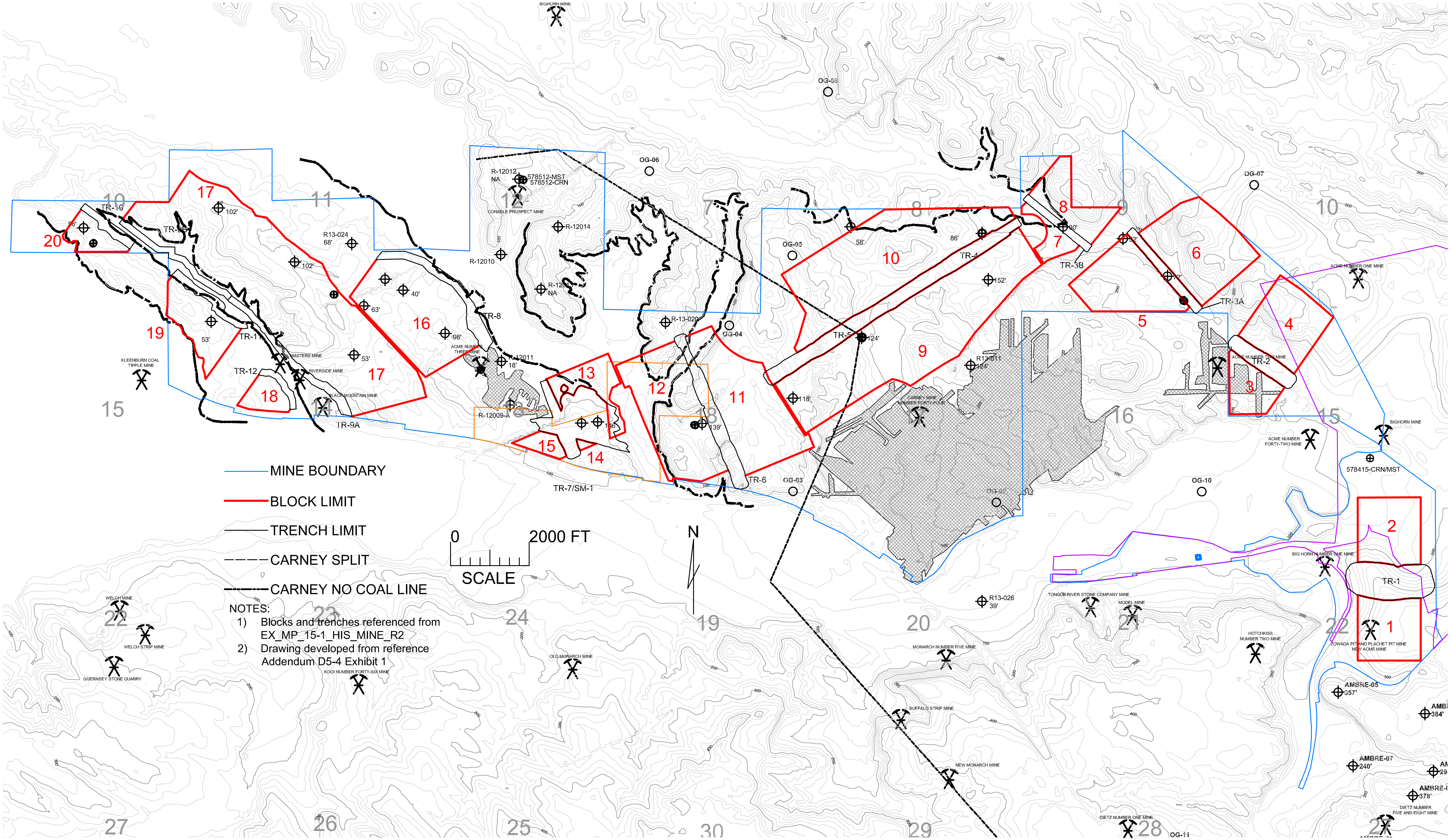

FIGURE 4.5 CARNEY COAL SEAM OVERBURDEN ISOPACH MAP (UPPER CARNEY WEST OF CARNEY SPLIT) WITH PROPOSED MINE LAYOUT

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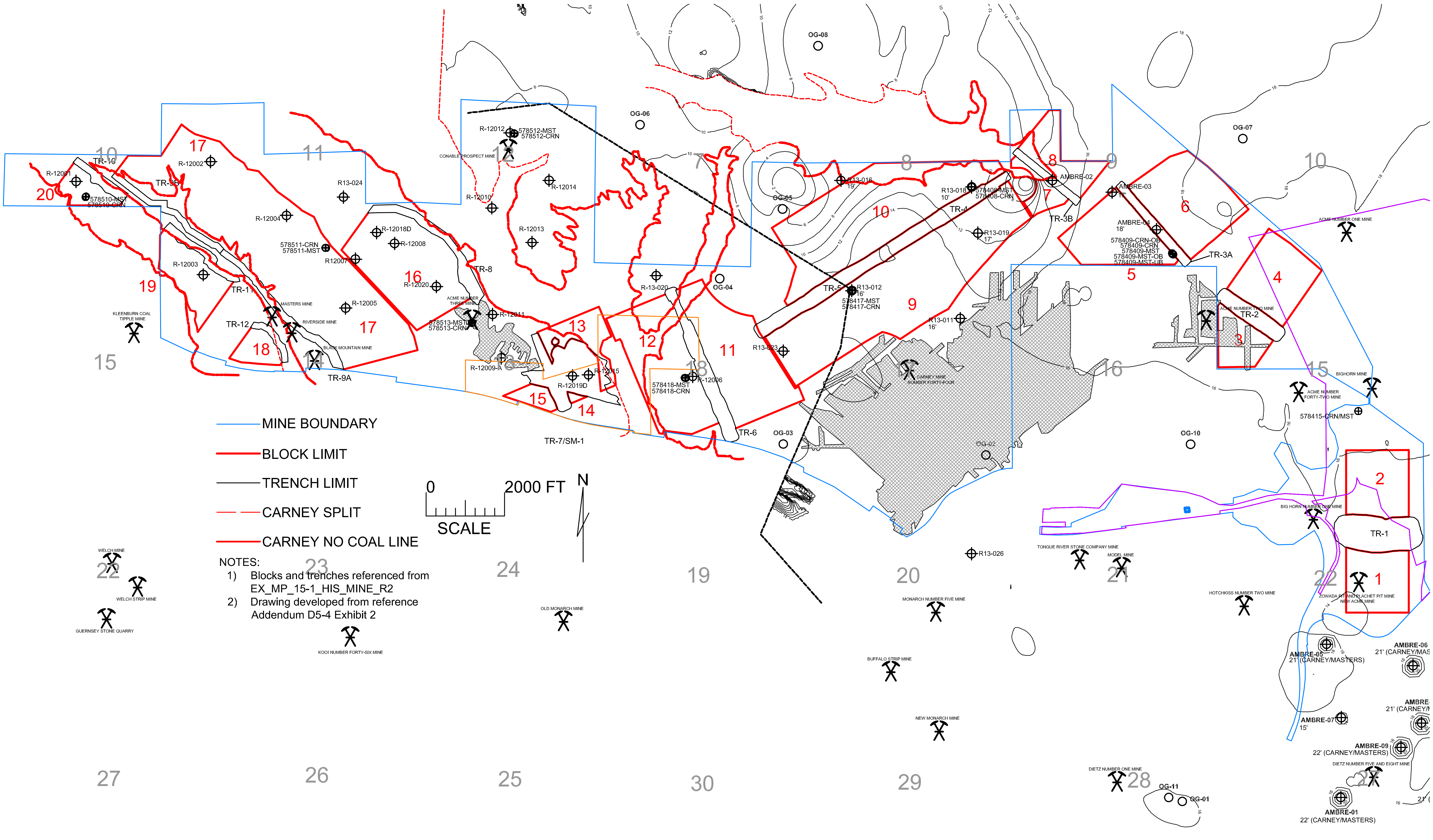

FIGURE 4.6 CARNEY COAL SEAM THICKNESS ISOPACH EAST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

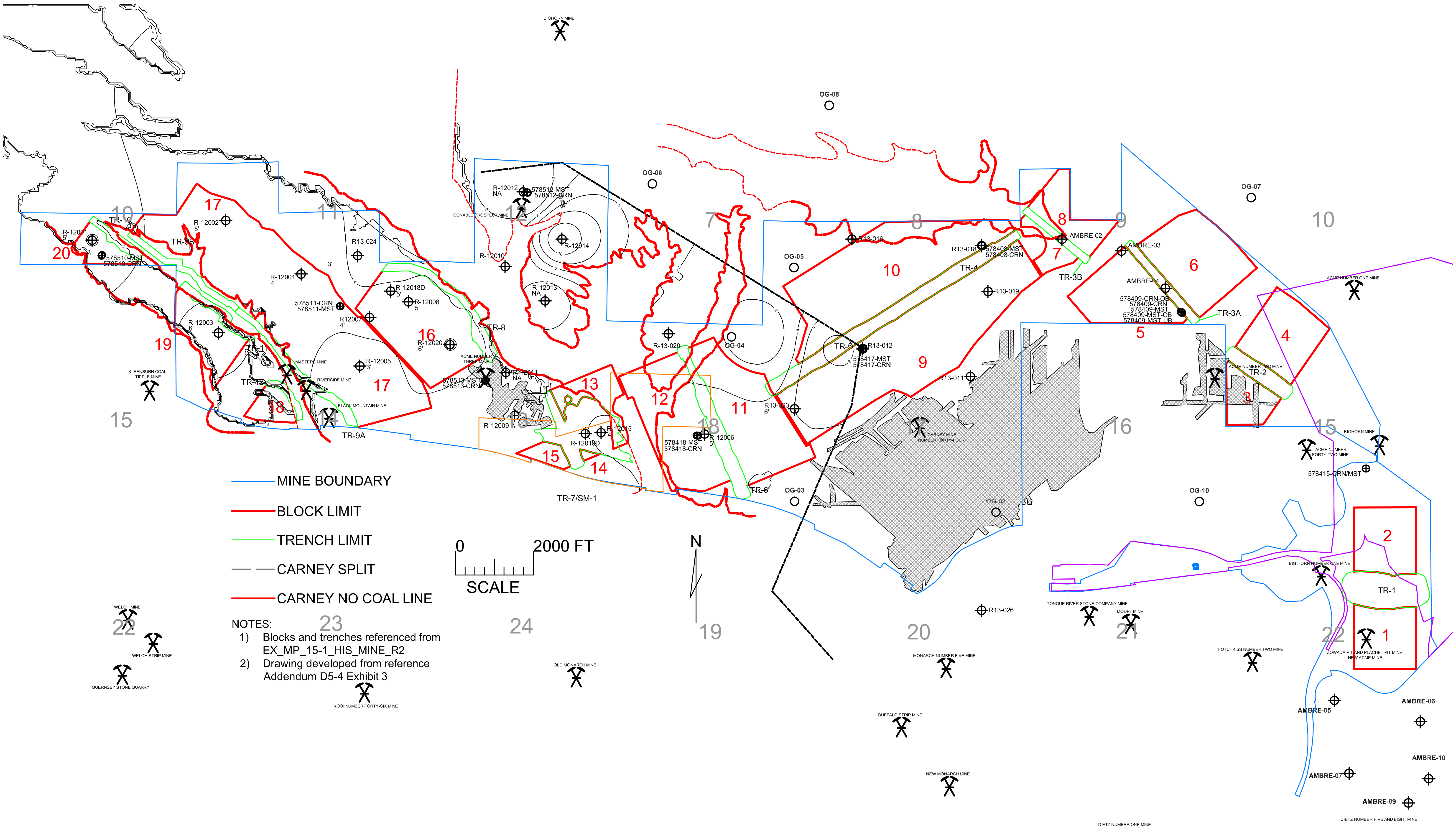

FIGURE 4.7 UPPER CARNEY COAL SEAM THICKNESS ISOPACH MAP WEST OF CARNEY SEAM SPLIT WITH PROPOSED MINE LAYOUT

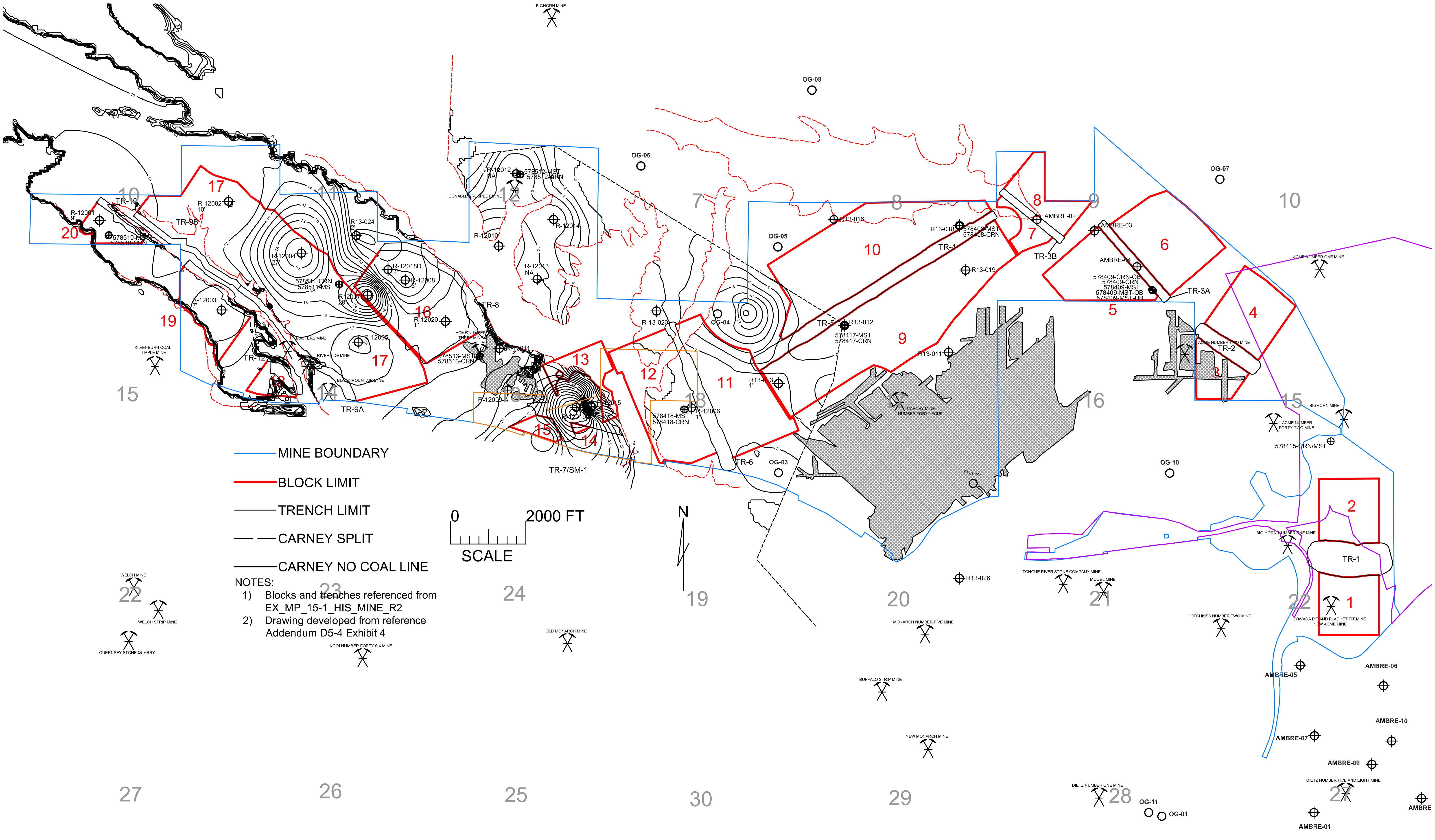

FIGURE 4.8 UPPER AND LOWER CARNEY COAL SEAM INTERBURDEN ISOPACH MAP, WEST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

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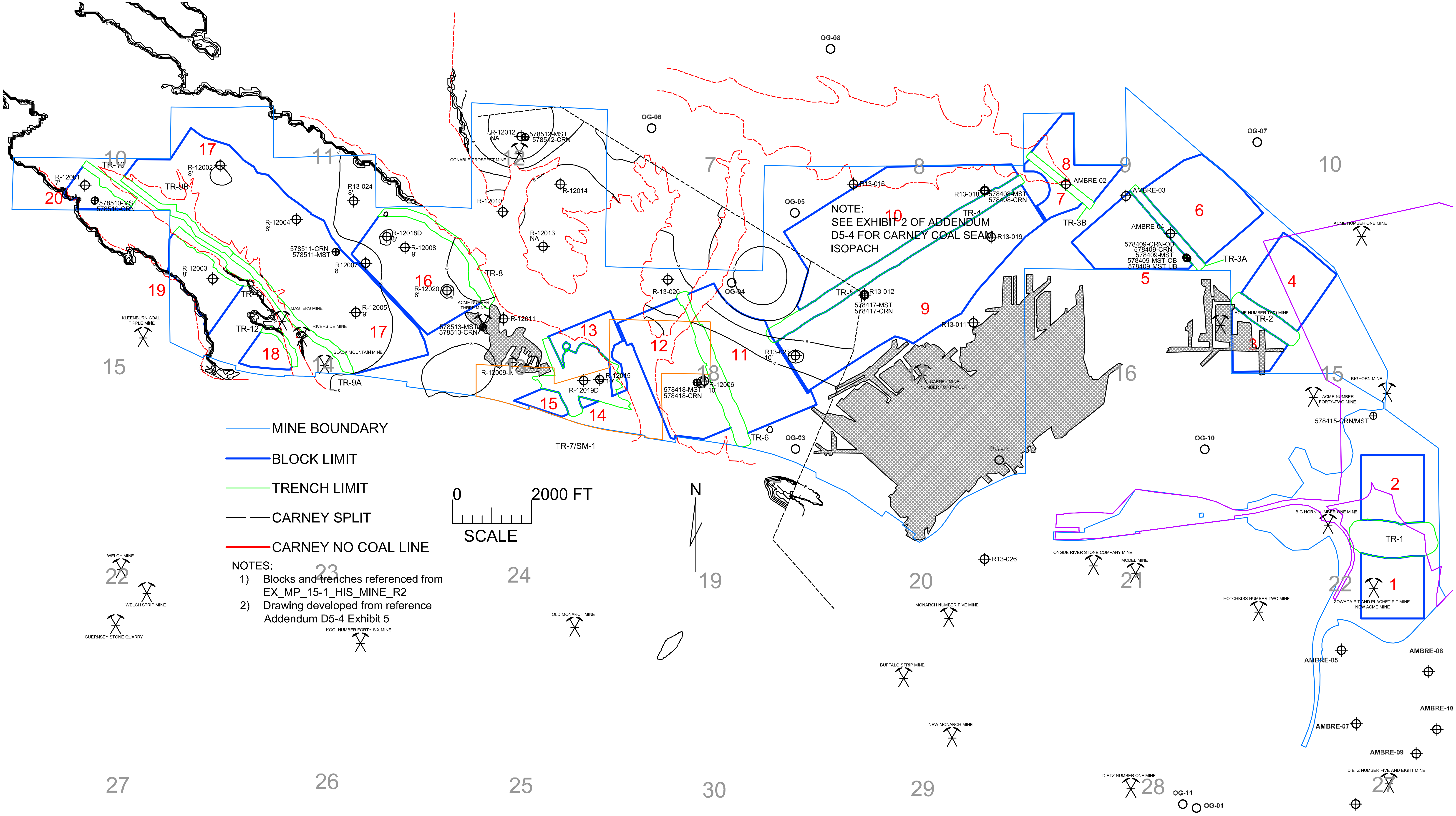

FIGURE 4.9 LOWER CARNEY COAL SEAM THICKNESS ISOPACH MAP, WEST OF SEAM SPLIT WITH PROPOSED MINE LAYOUT

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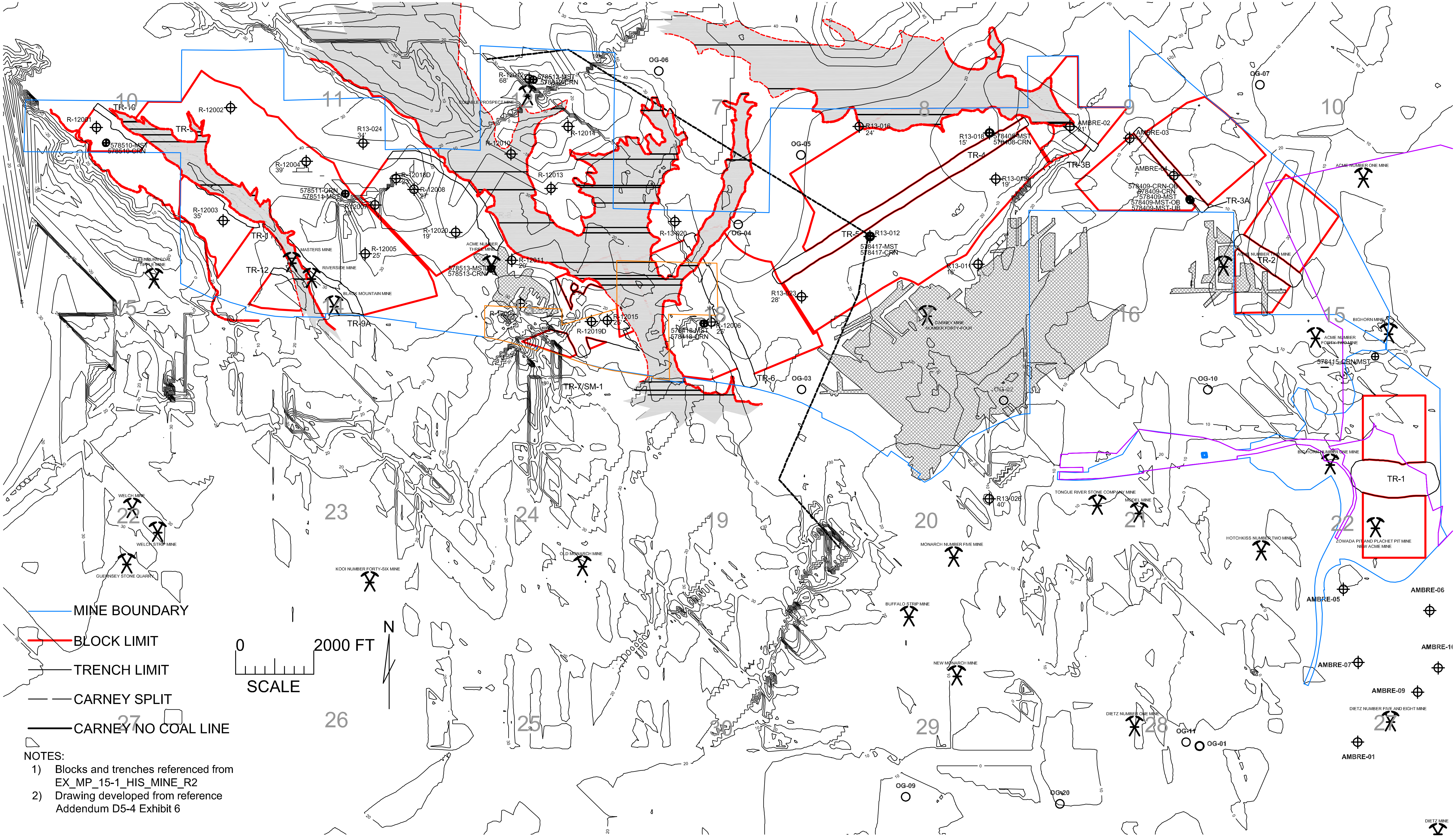

FIGURE 4.10 CARNEY AND MASTERS COAL SEAM INTERBURDEN ISOPACH MAP WITH PROPOSED MINE LAYOUT

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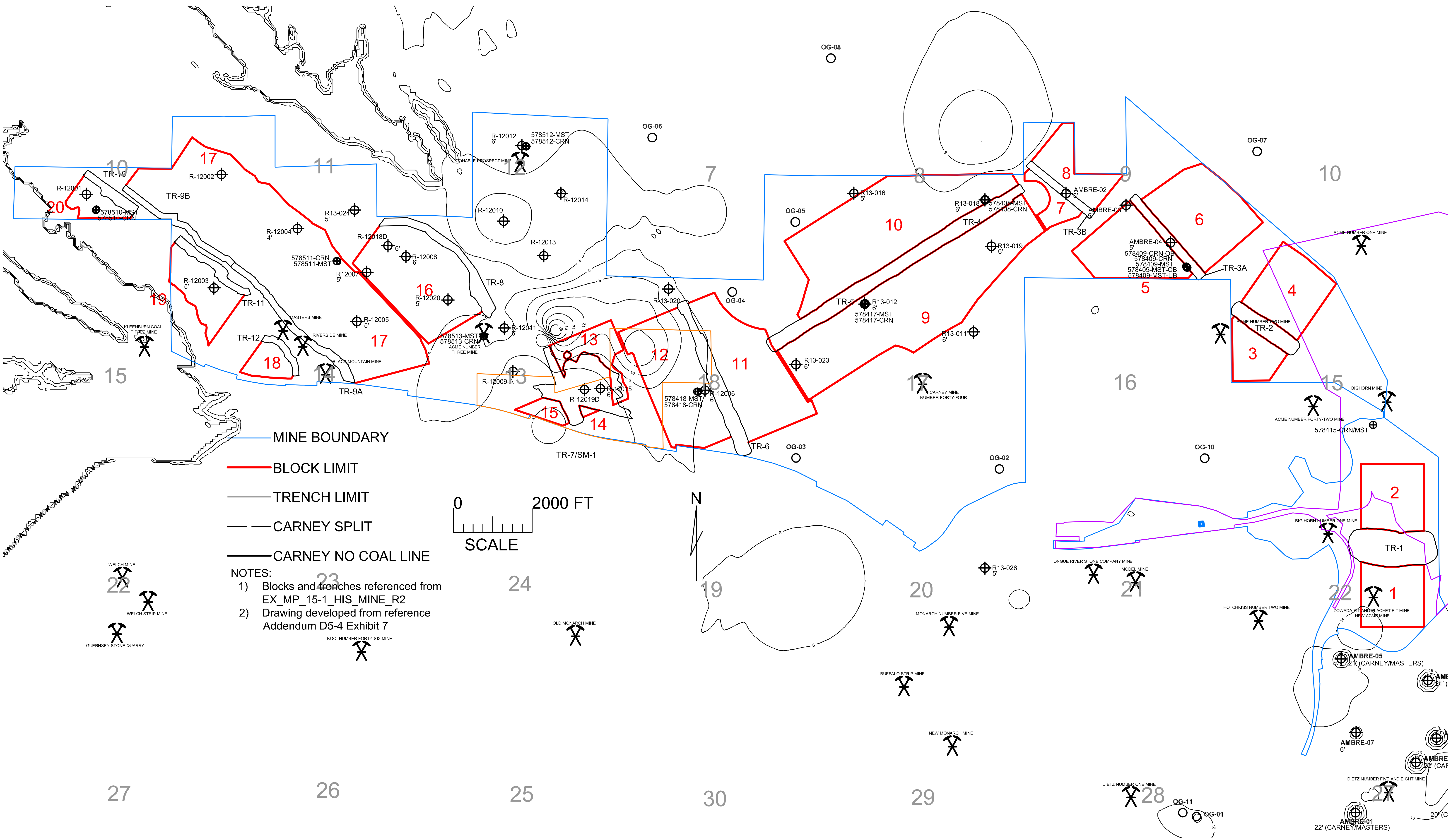

FIGURE 4.11 MASTERS COAL THICKNESS ISOPACH WITH PROPOSED MINE LAYOUT

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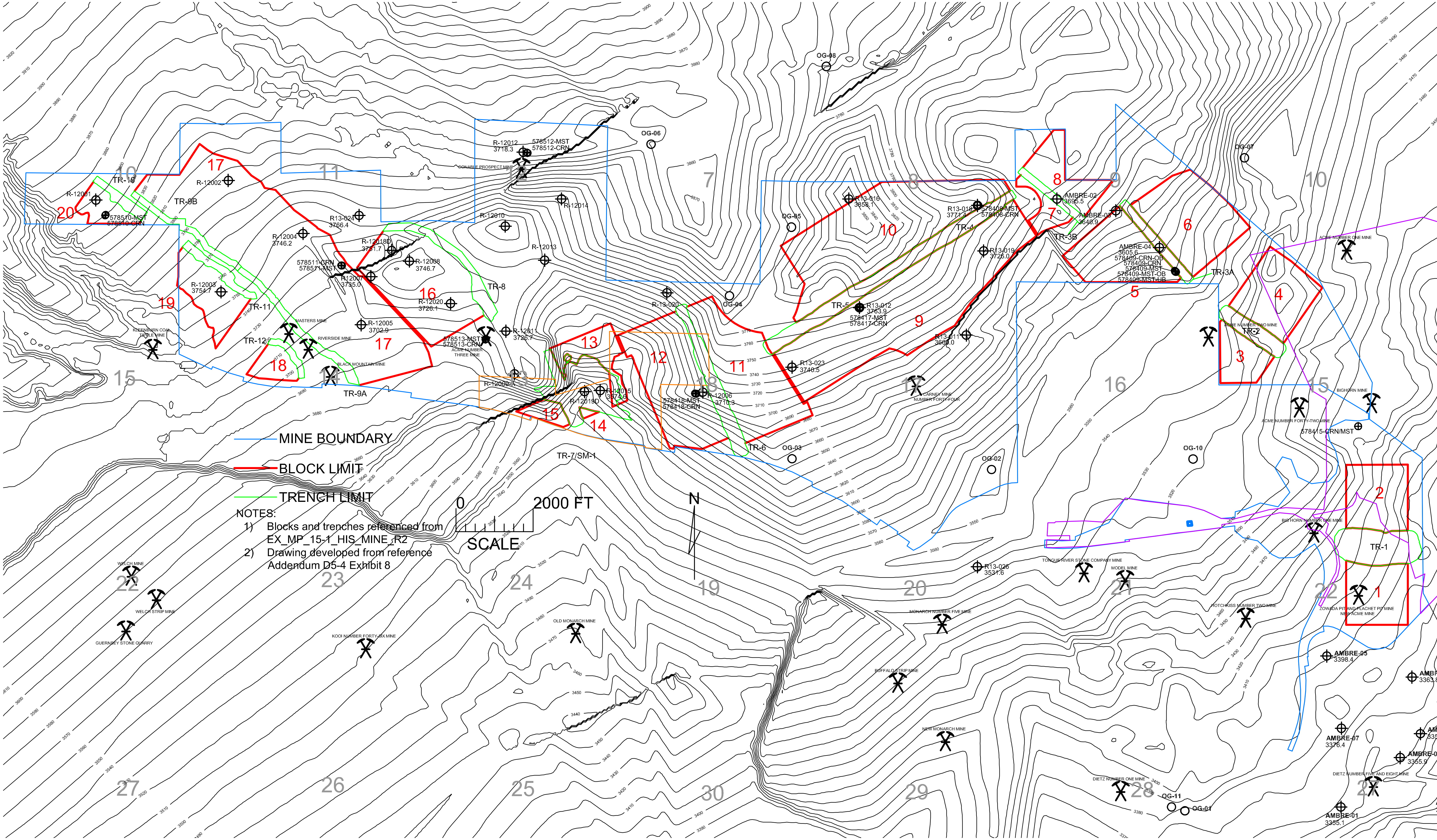

FIGURE 4.12 MASTERS COAL BOTTOM ELEVATION ISOPACH WITH PROPOSED MINE LAYOUT

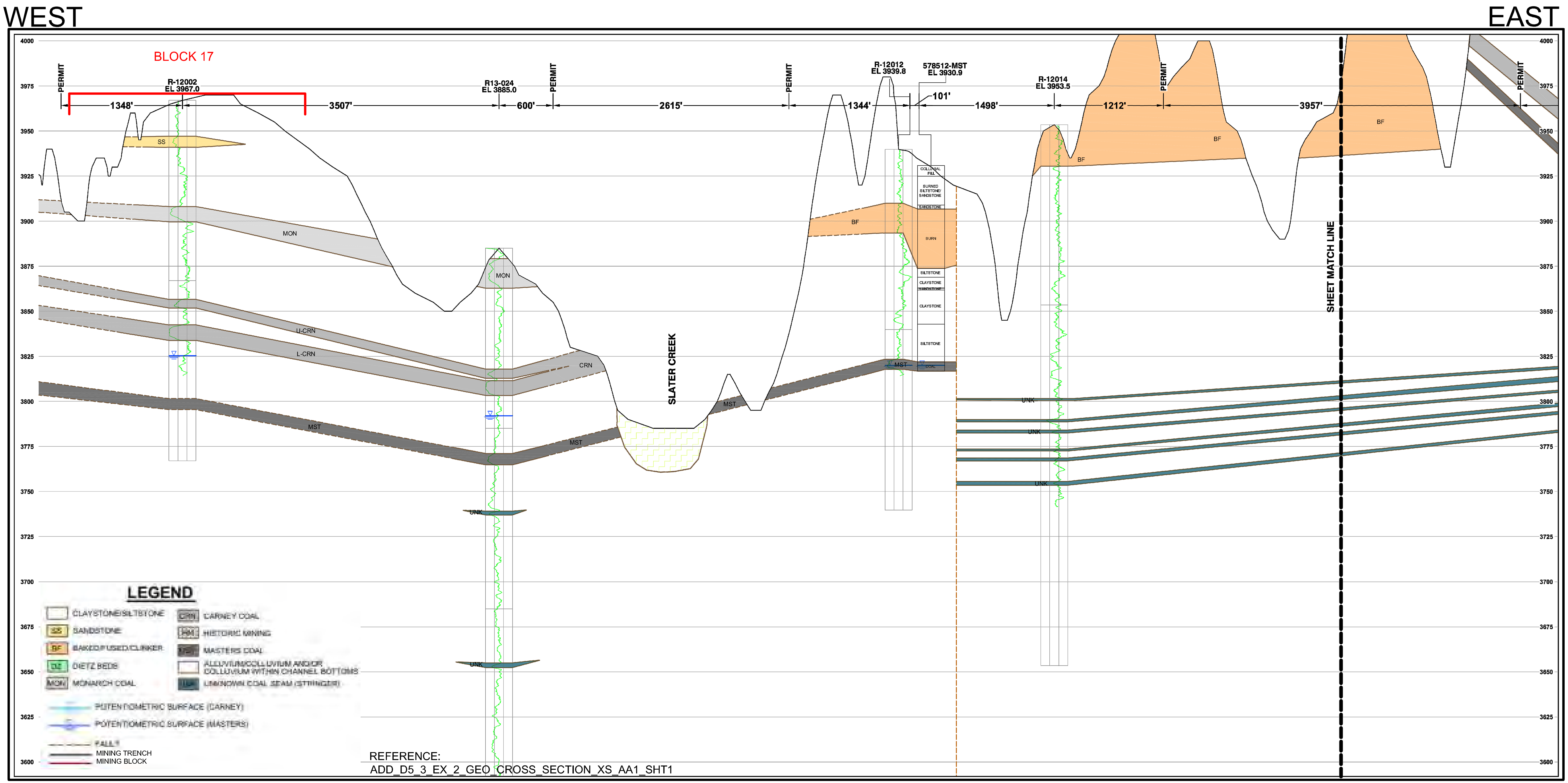

FIGURE 4.13 WEST SECTION OF CROSS-SECTION A-A' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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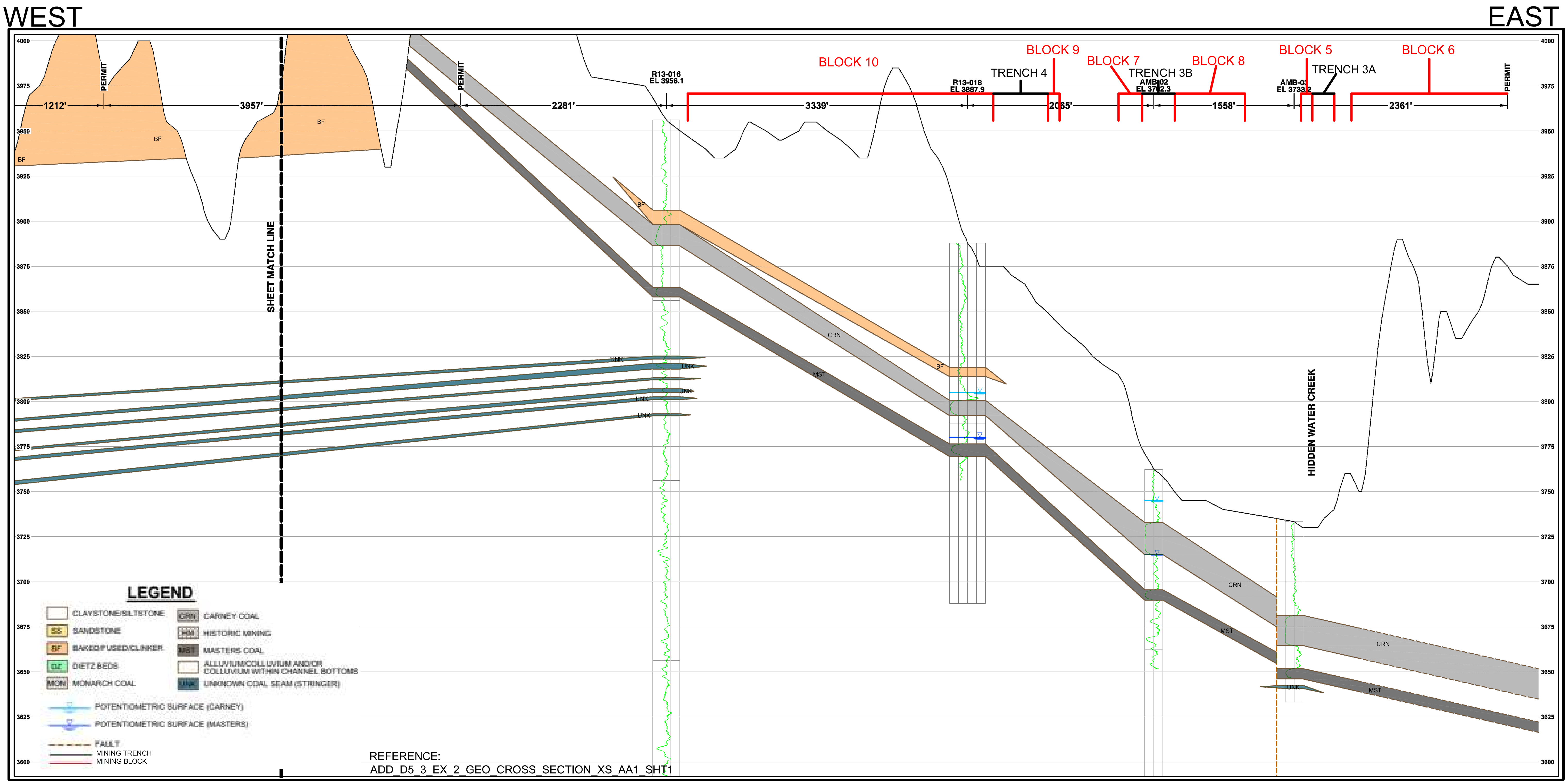

FIGURE 4.14 EAST SECTION OF CROSS-SECTION A-A' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED RAMACO MINE

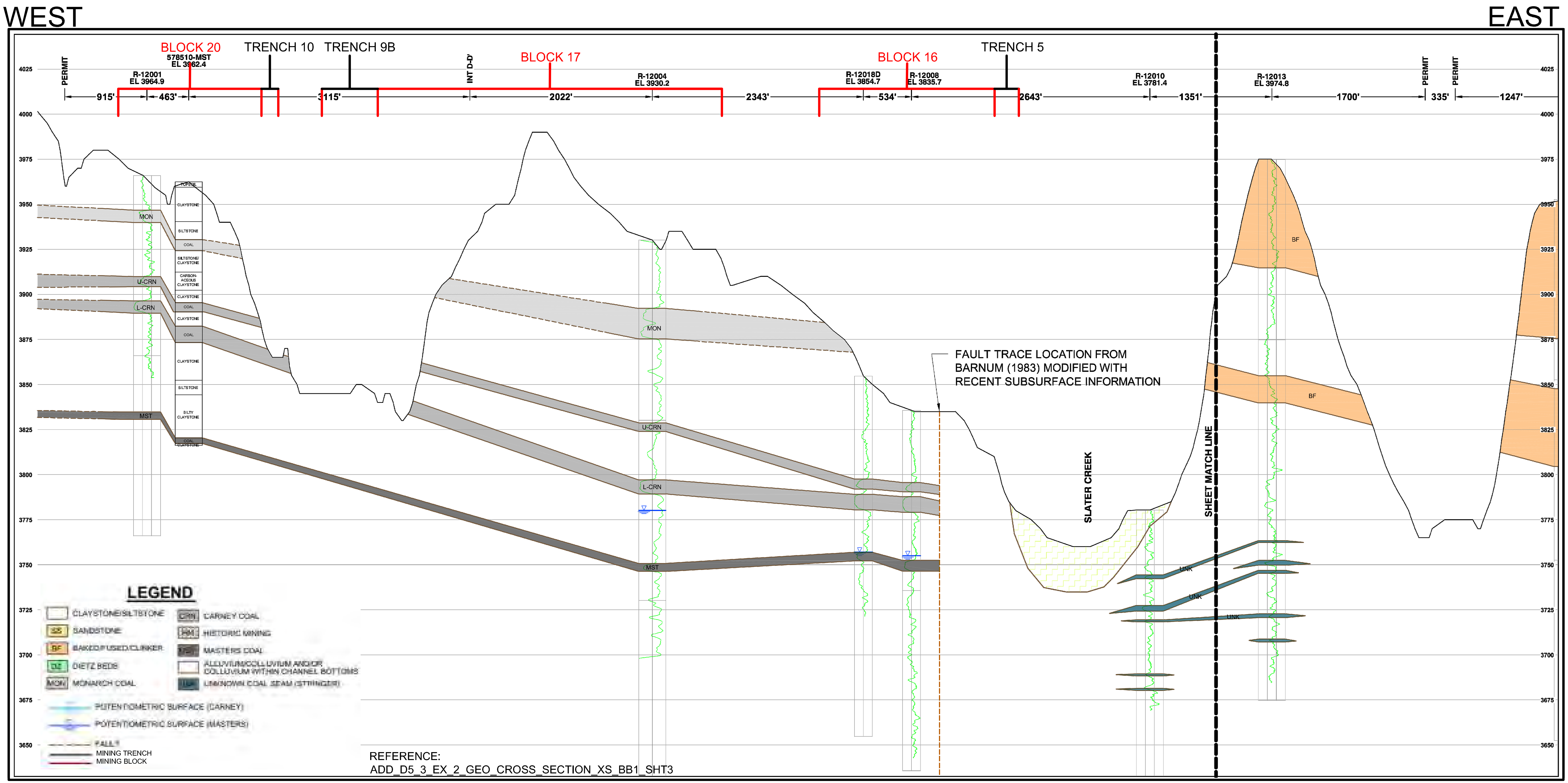

FIGURE 4.15 WEST SECTION OF CROSS-SECTION B-B' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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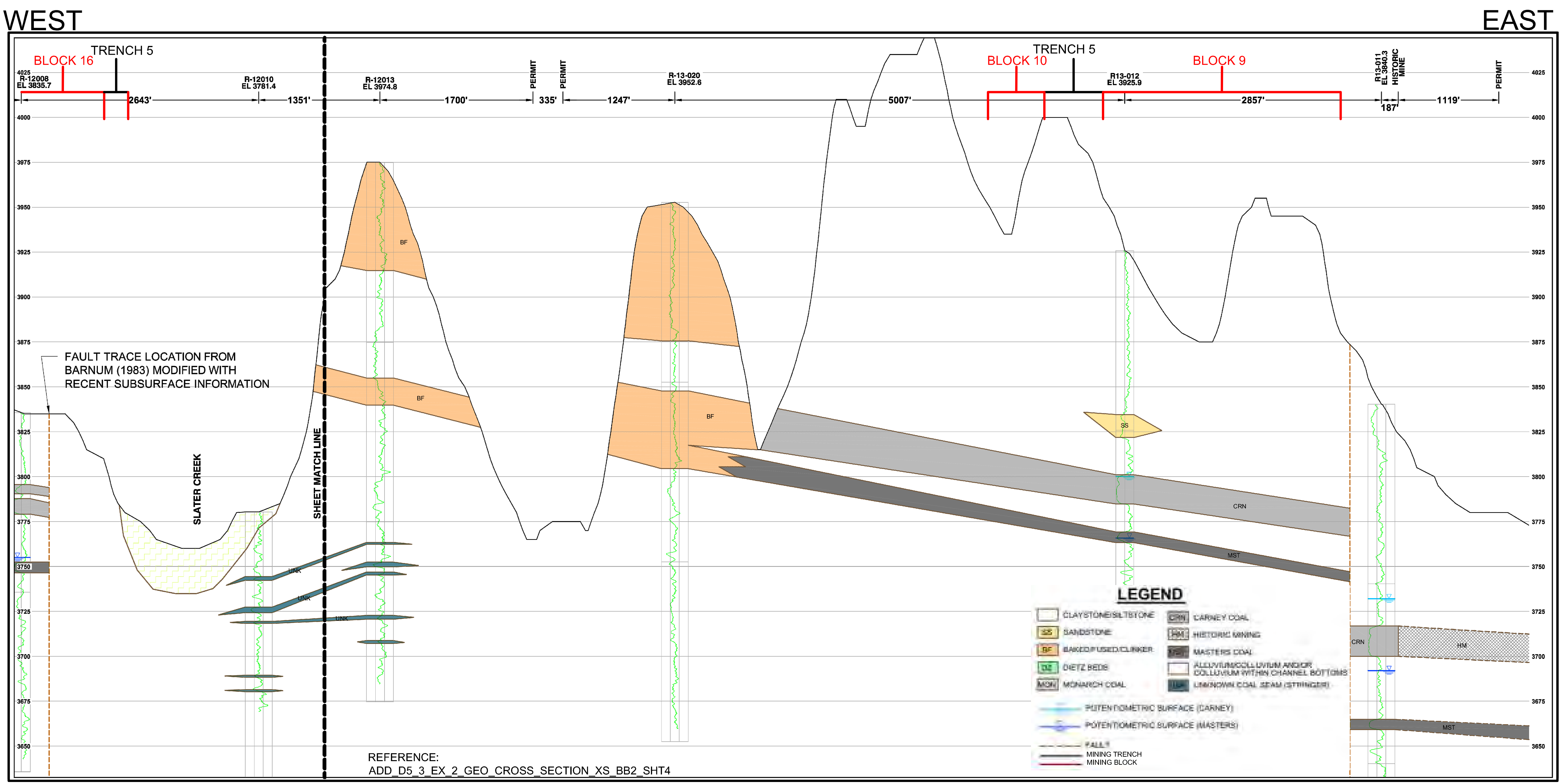

FIGURE 4.16 EAST SECTION OF CROSS-SECTION B-B' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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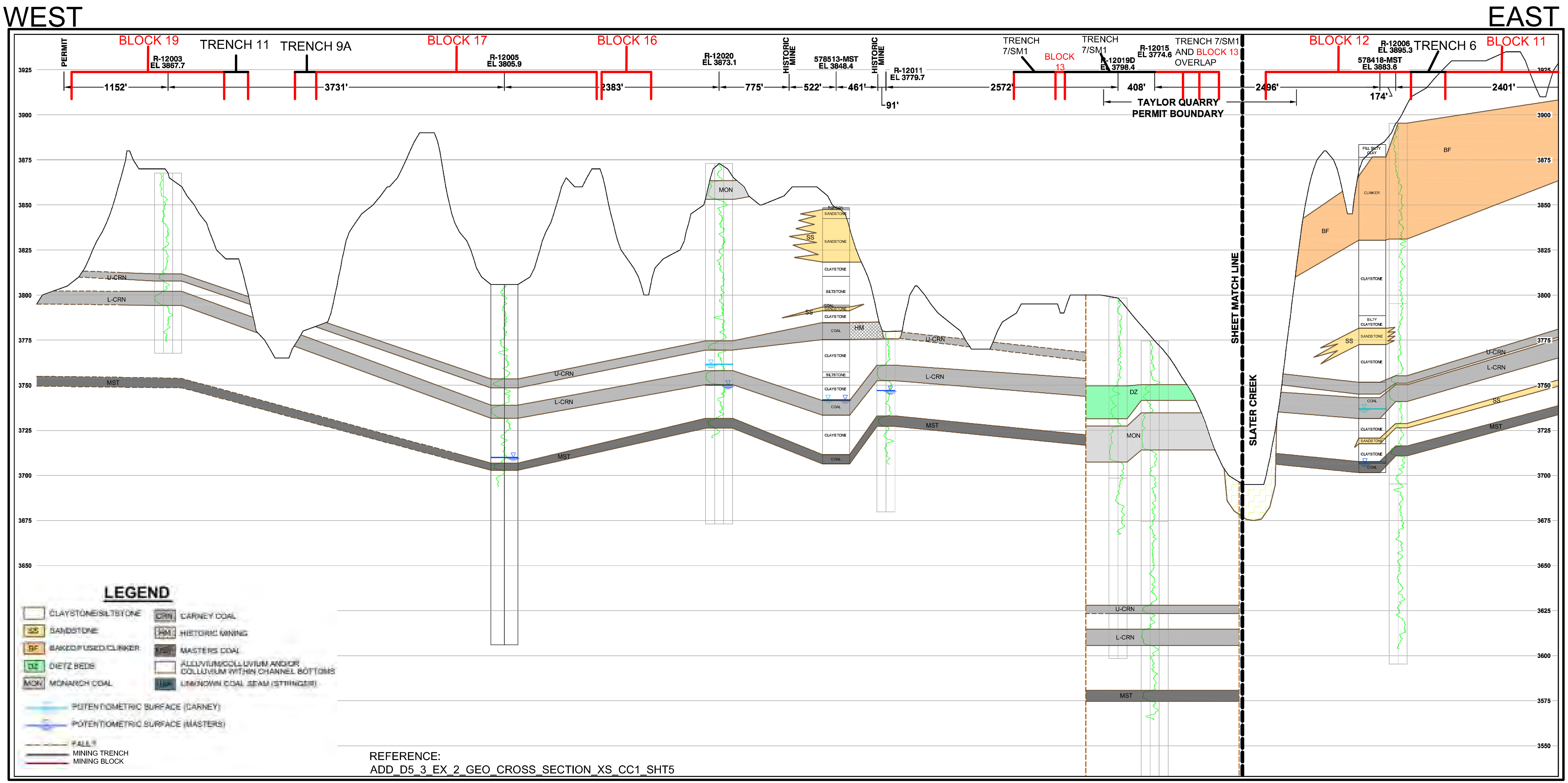

FIGURE 4.17 WEST SECTION OF CROSS-SECTION C-C' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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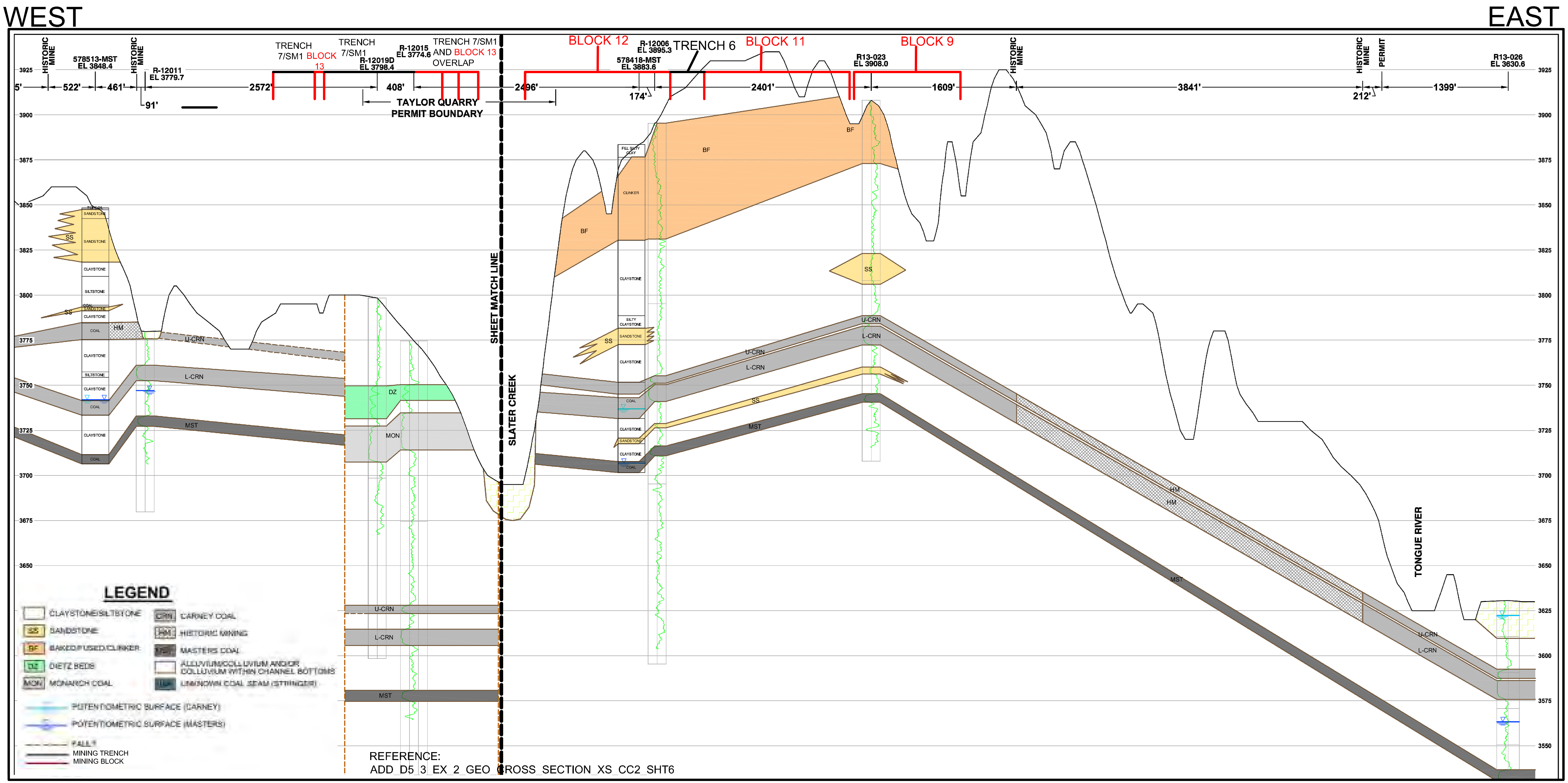

FIGURE 4.18 EAST SECTION OF CROSS-SECTION C-C' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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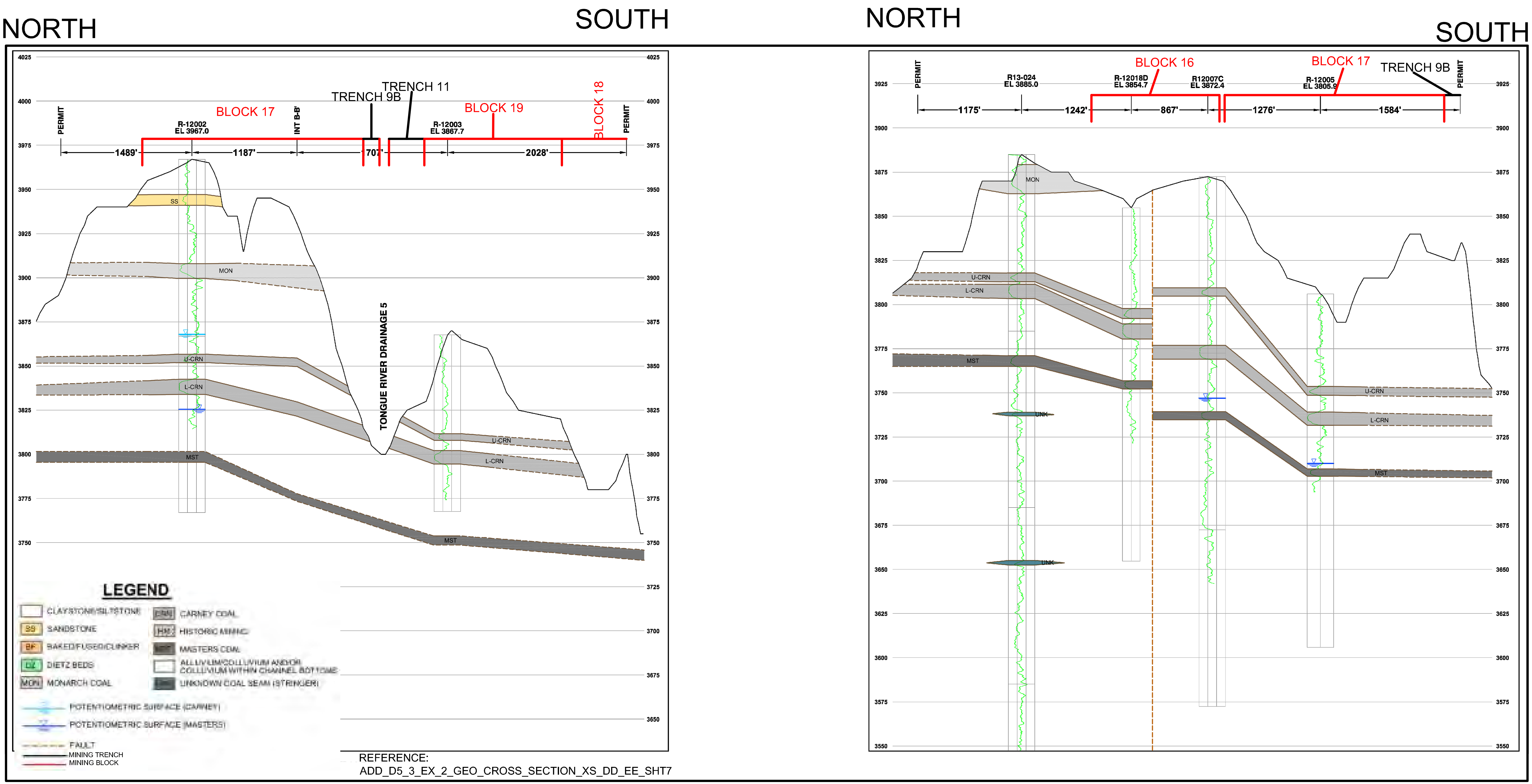

FIGURE 4.19 CROSS-SECTION D-D' AND E-E' SHOWING MINING BLOCK AND TRENCH EXTENTS OF THE PROPOSED BROOK MINE

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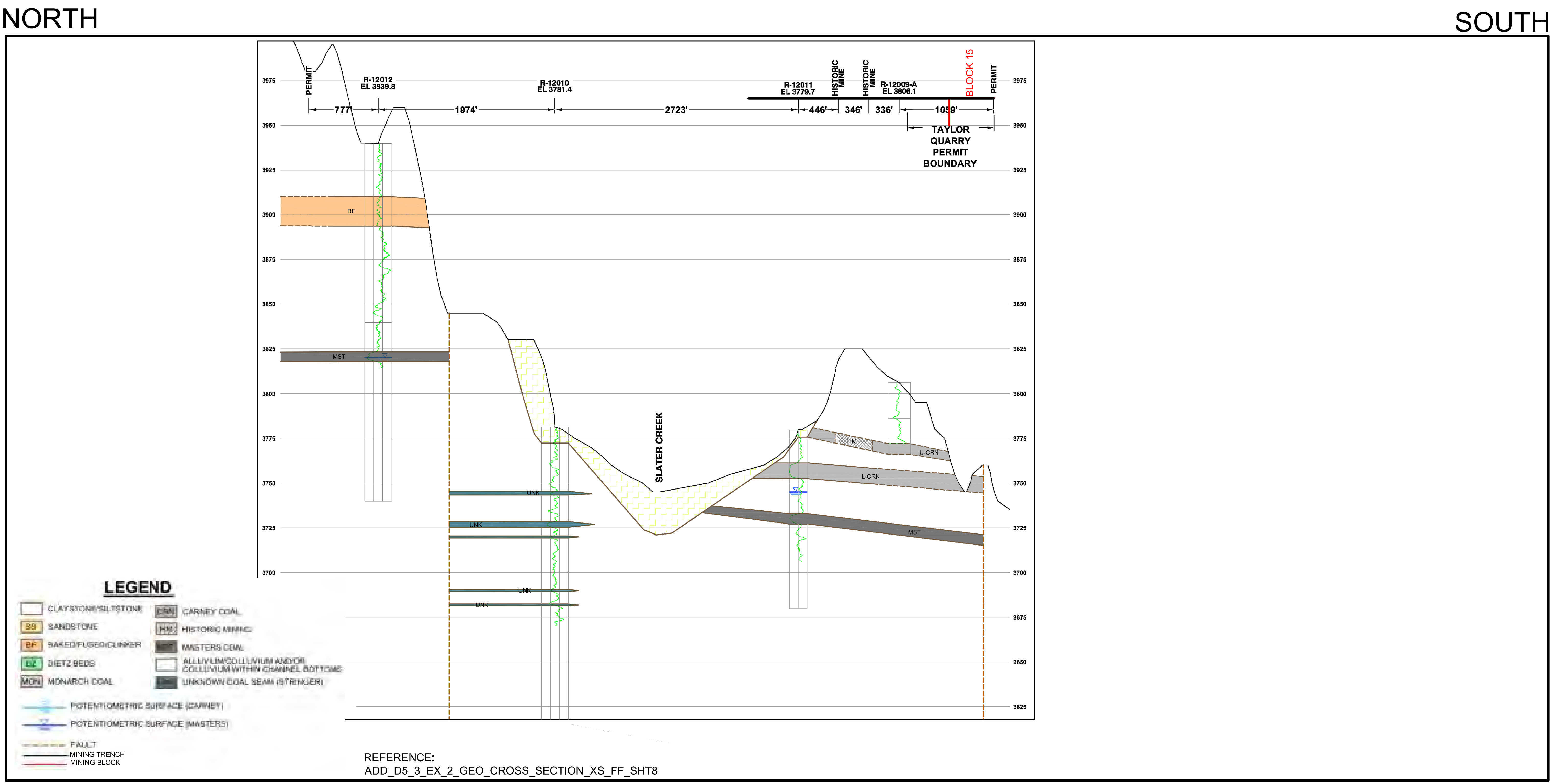

FIGURE 4.20 CROSS-SECTION F-F' FOR THE PROPOSED BROOK MINE (NO MINING IS PLANNED ALONG THIS CROSS-SECTION)

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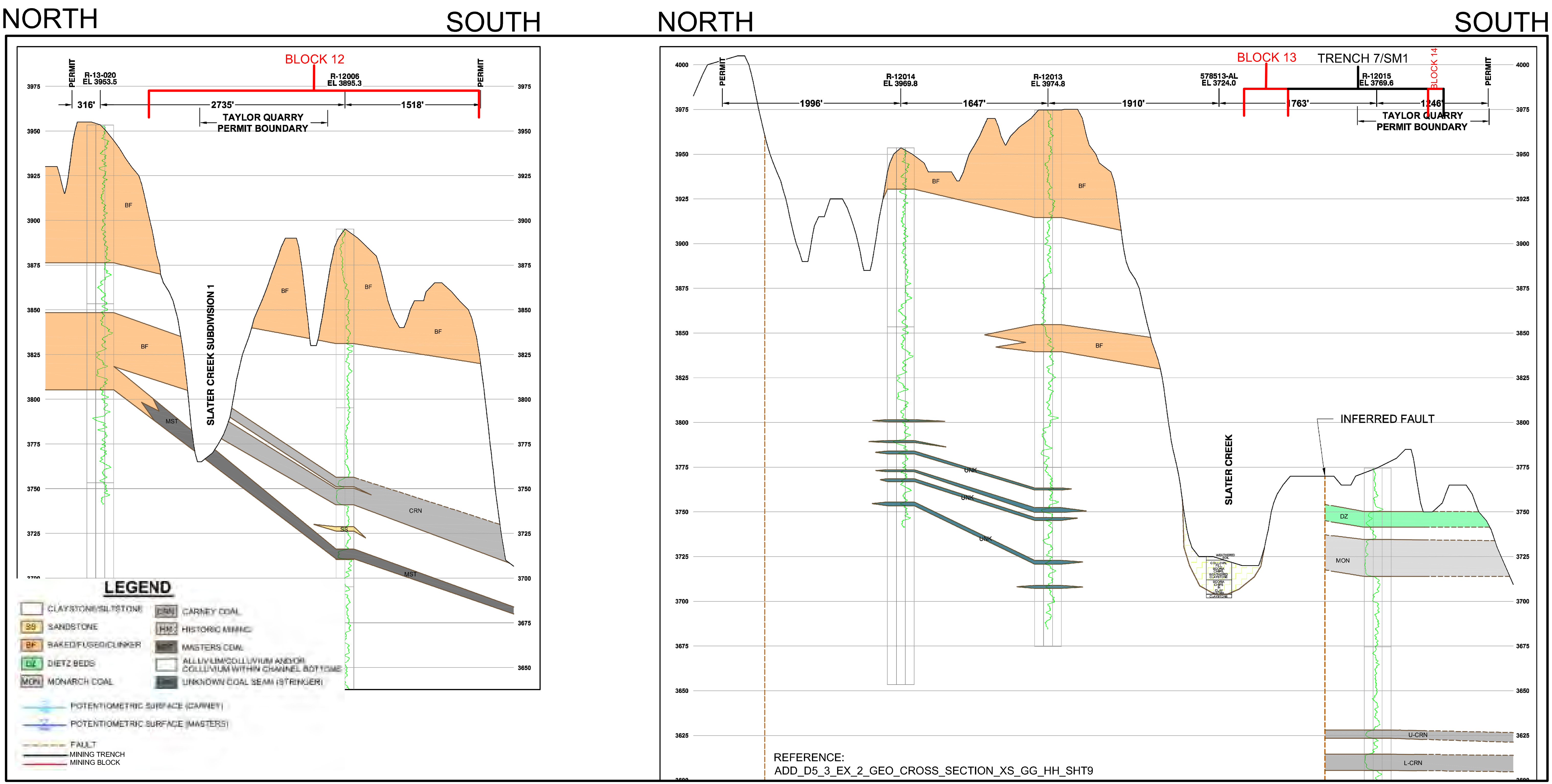

FIGURE 4.21 CROSS-SECTIONS G-G' AND H-H' SHOWING MINING BLOCK AND TRENCH EXTENTS FOR THE PROPOSED BROOK MINE

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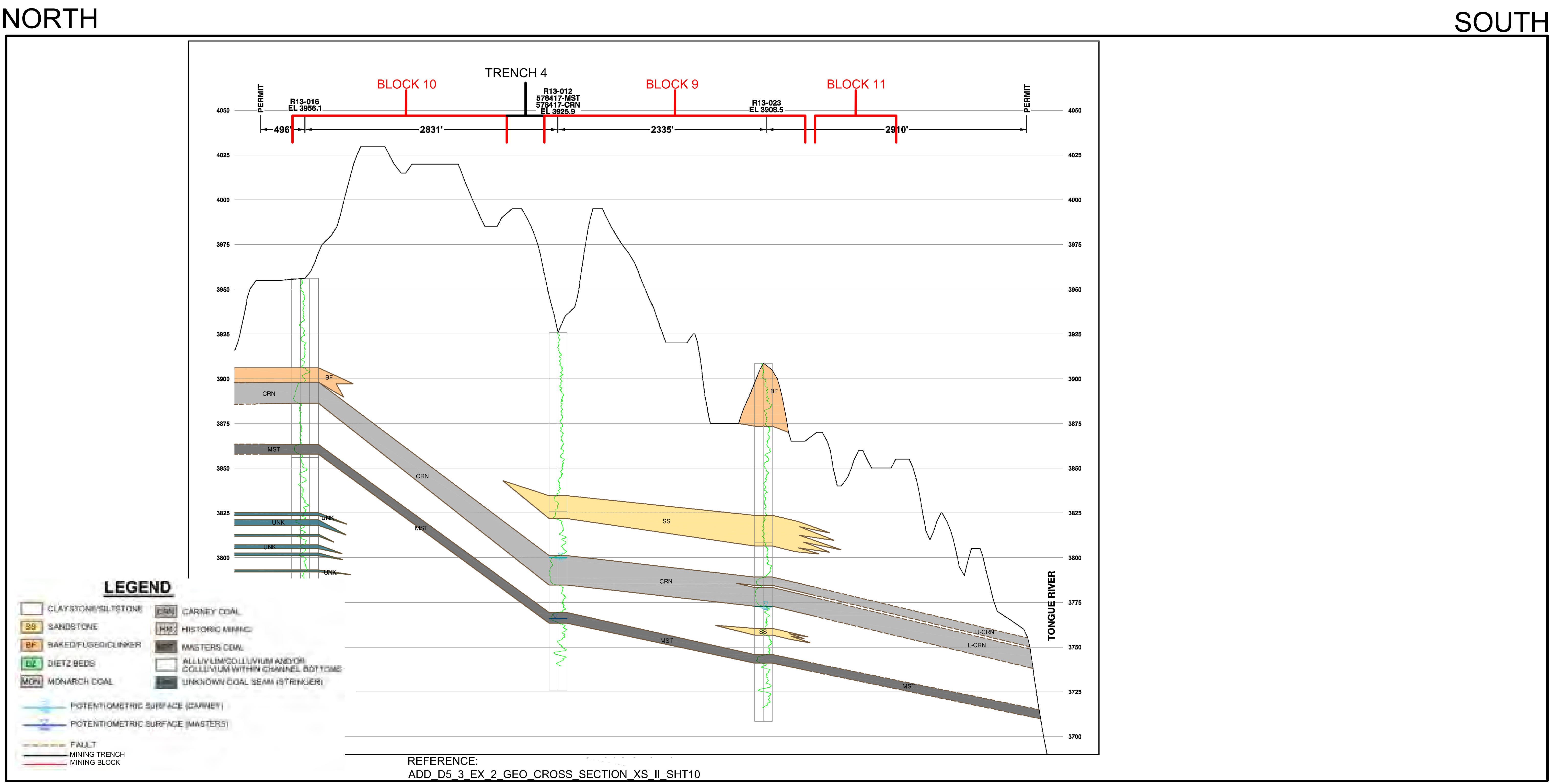

FIGURE 4.22 CROSS-SECTION I-I' SHOWING MINING BLOCK AND TRENCH EXTENTS FOR THE PROPOSED BROOK MINE

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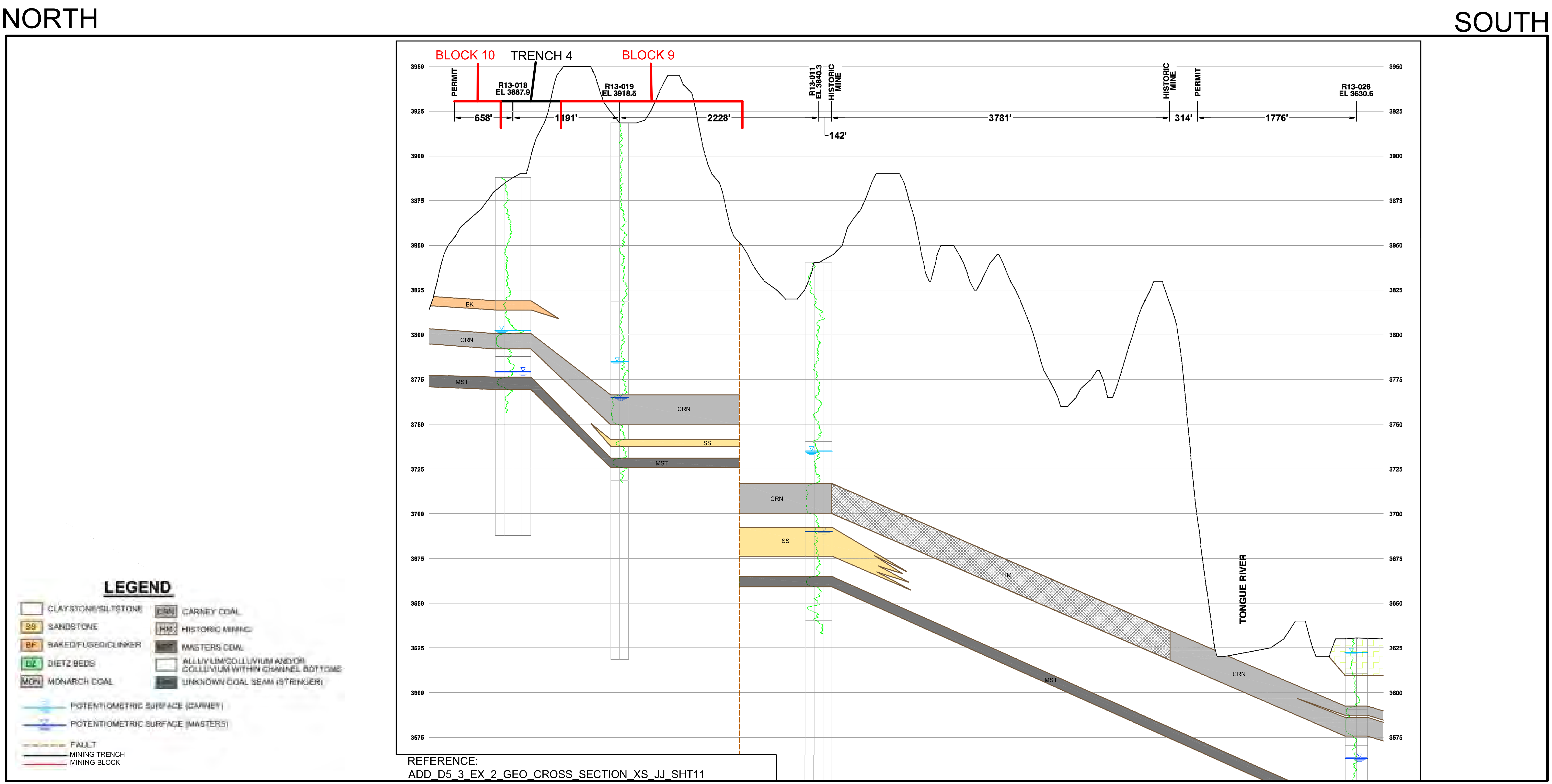

FIGURE 4.23 CROSS-SECTION J-J' SHOWING MINING BLOCK AND TRENCH EXTENTS FOR THE PROPOSED BROOK MINE

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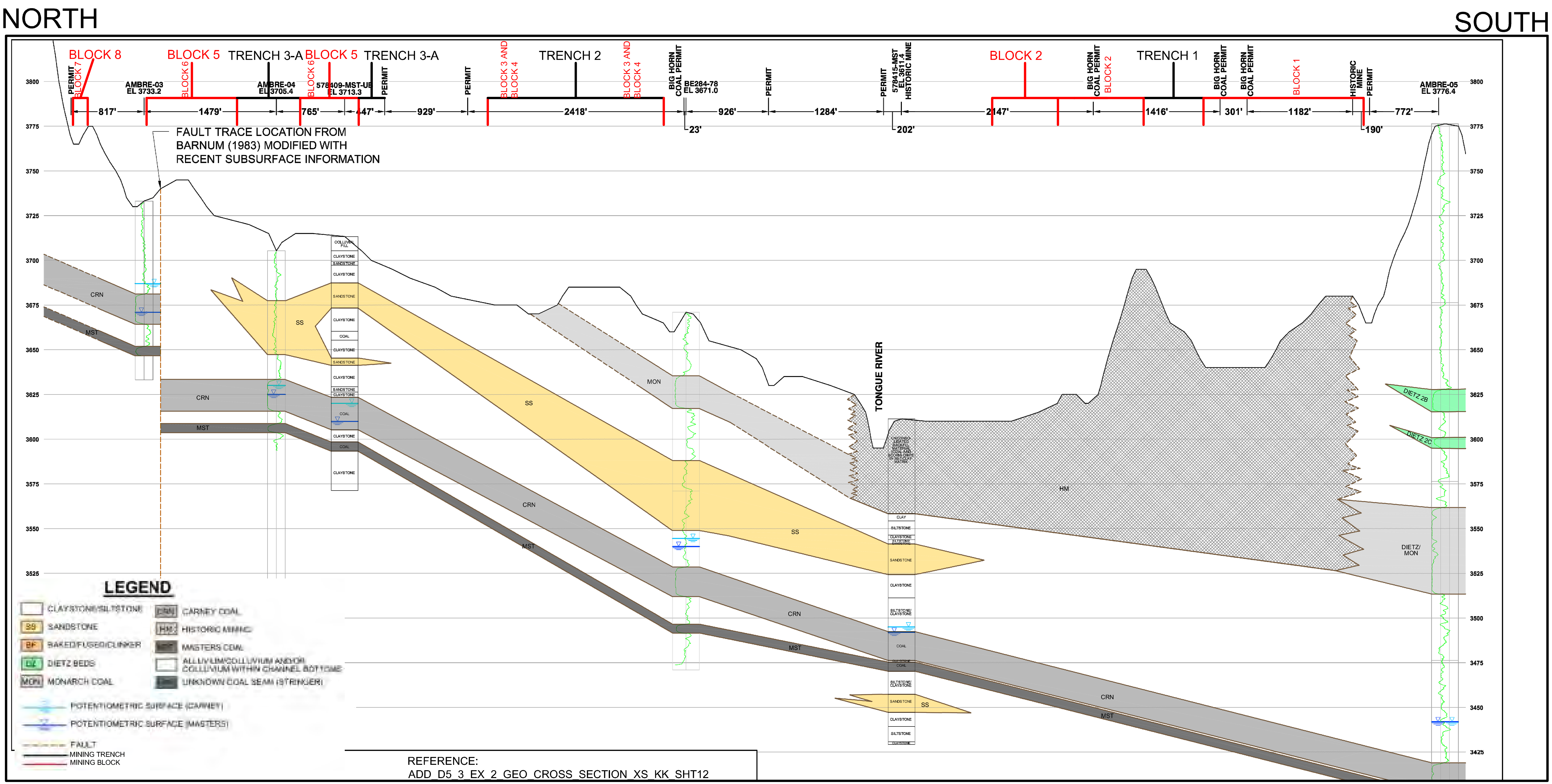

FIGURE 4.24 CROSS-SECTION K-K' SHOWING MINING BLOCK AND TRENCH EXTENTS FOR THE PROPOSED BROOK MINE

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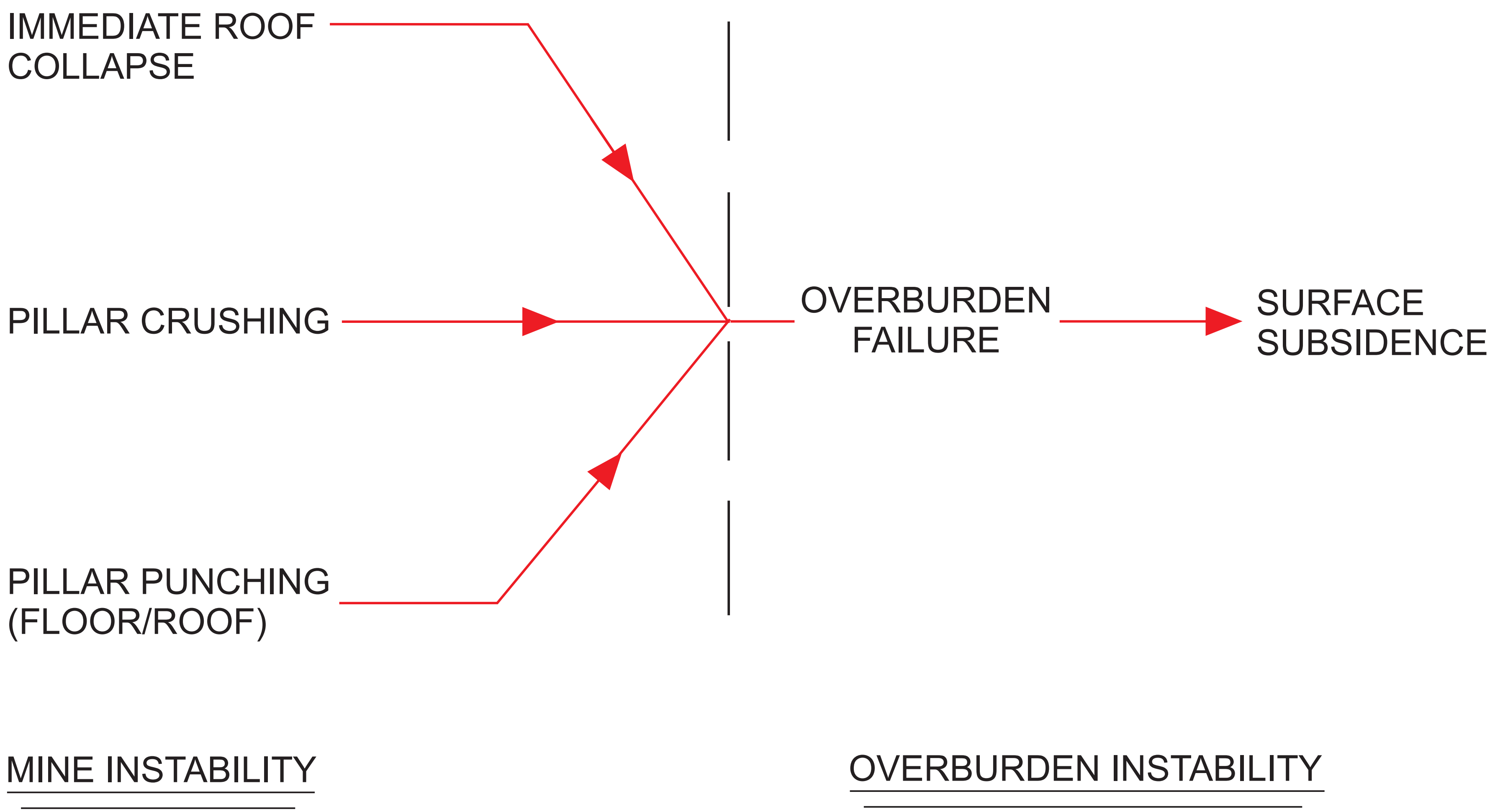

FIGURE 5.1 SUBSIDENCE FAILURE MECHANICS OF ROOM-AND-PILLAR WORKINGS AND THE OVERBURDEN

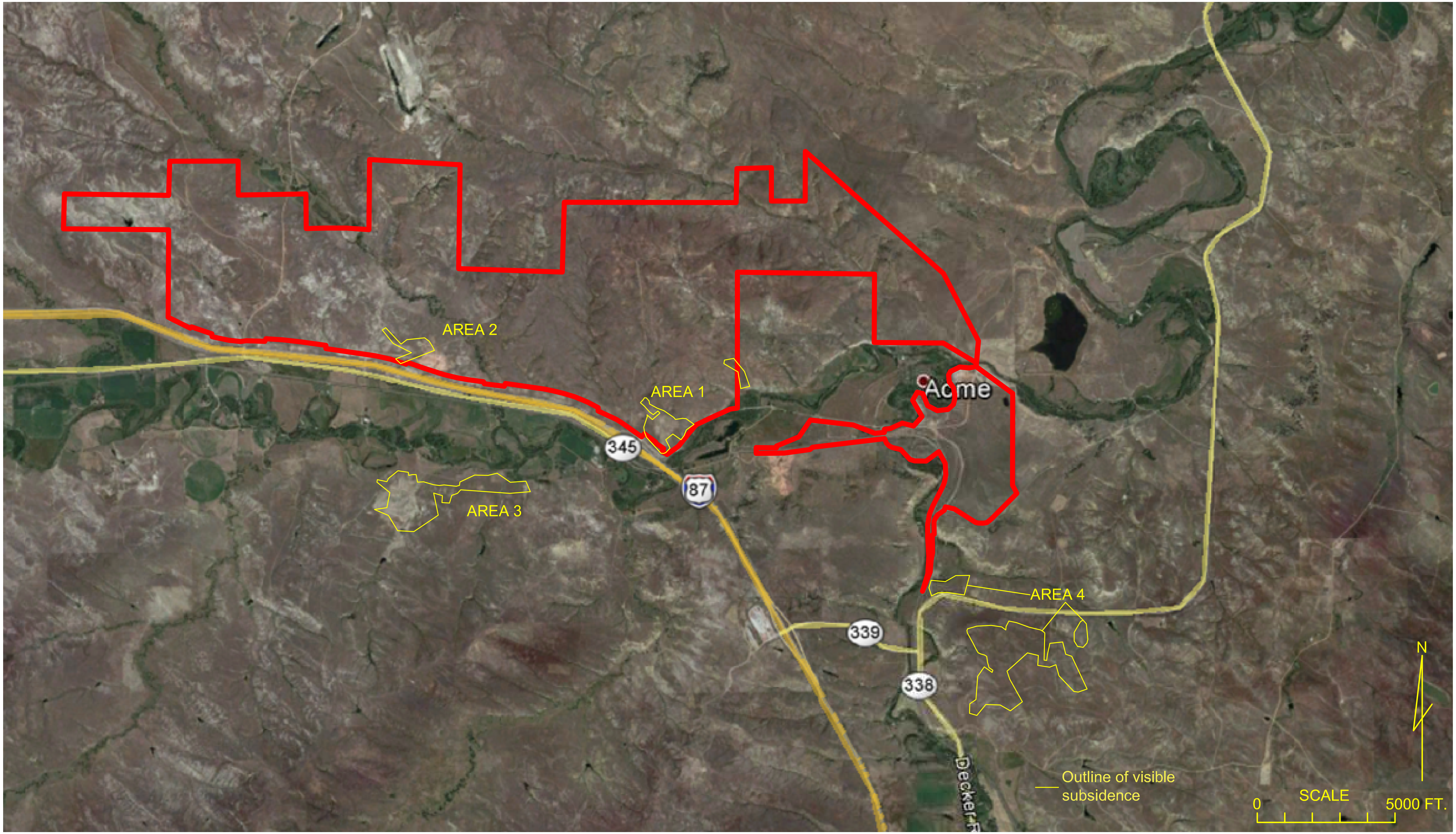

FIGURE 7.1 MINE APPLICATION BOUNDARY AND OUTLINE OF VISIBLE MINE SUBSIDENCE OVER EXISTING UNDERGROUND WORKINGS

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FIGURE 7.2 AREA 1 MINE SUBSIDENCE FROM UNDERGROUND MINING OF THE CARNEY NO. 44 MINE. MINE DEPTH IN NOTED SUBSIDENCE AREA RANGED FROM 50 TO 160 FT. (ADD_D5-4_EX_1_OVB_ISO_R1)

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FIGURE 7.3 AREA 2 MINE SUBSIDENCE FROM UNDERGROUND MINING OF THE OLD ACME NUMBER 3 MINE IN THE UPPER CARNEY SEAM. MINE DEPTH IN THE NOTED SUBSIDENCE AREA IS 60 TO ABOUT 160 FT. (ADD_D5-4_EX_1_OVB_ISO_R1).

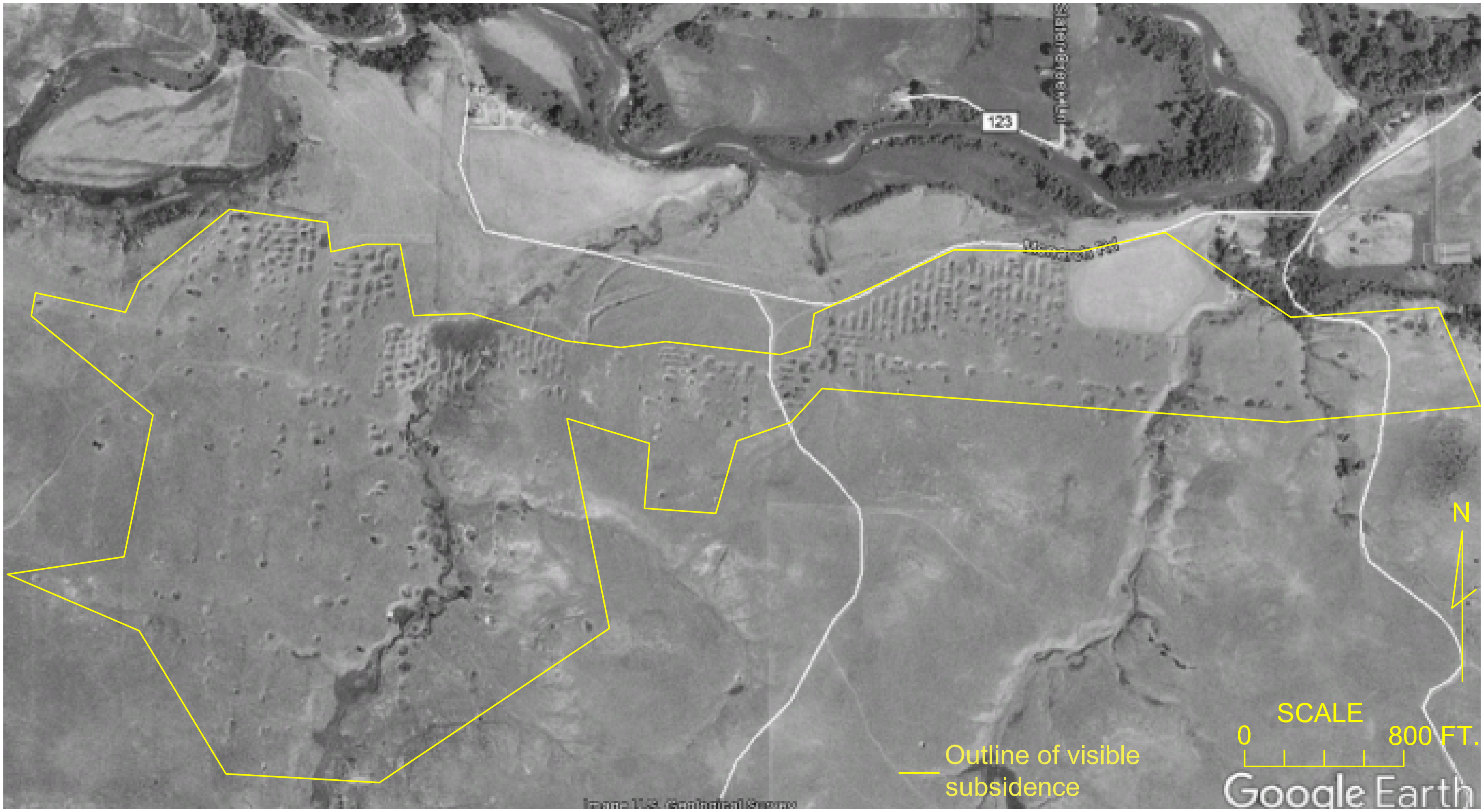

FIGURE 7.4 AREA 3 MINE SUBSIDENCE FROM UNDERGROUND MINING OF THE OLD MONARCH MINE IN THE MONARCH SEAM. MINE DEPTH IS APPROXIMATELY 35-50FT (DUNRUD, C. R., AND OSTERWALD, F.W., 1980).

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FIGURE 7.5 AREA 4 MINE SUBSIDENCE FROM UNDERGROUND MINING OF DIETZ MINES NO. 5 TO 8. IN THE DIETZ COAL SEAMS AT ROUGHLY 20 TO 150 FT. BELOW GROUND SURFACE (DUNRUD, C. R., AND OSTERWALD, F.W., 1980).

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TABLE 3.1 SUMMARY OF LABORATORY TEST RESULTS ON ROCK MOISTURE, DENSITY, AND BRAZILIAN AND UNIAXIAL COMPRESSION STRENGTHS

SAMPLE	BORING	DEPTH	MOISTURE CONTENT	WET DENSITY	BRAZILIAN TENSILE STRENGTH	UNIAXIAL COMPRESSION STRENGTH	REMARKS
CLAYSTONE	R13-019	150-152 FT.	10.0%	139 pcf	170 psi	--	immediate roof
CARNEY COAL	R13-019	152-153 FT.	25.0%	80.9 pcf	90 psi	1,460 psi	
SILTSTONE WITH CLAY	R13-019	168-169 FT.	8.8%	144.8 pcf	60 psi	500 psi	immediate floor
SILTSTONE	R13-023	110-112 FT.	7.9%	159.4 pcf	440 psi	3,500 psi	likely siltstone, main roof of the Upper Carney
COAL	R13-023	110-112 FT.	20.1%	79.1 pcf	--	--	Coal is not described at this depth - Upper Carney?

References: D5-5-4, D5-5-8, D5-5-10, D5-5-12

TABLE 4.1 DIETZ, MONARCH, CARNEY, AND MASTERS RELATED CONDITIONS PER BLOCK

MINE BLOCK	COAL SEAM	HEIGHT OF SEAM (FT.)	DEPTH OF SEAM TOP (FT.)	ROOF		FLOOR	
				HEIGHT (FT.)	THICKNESS (FT.)	DEPTH (FT.)	THICKNESS (FT.)
1	MONARCH	41	100-1115				
1	CARNEY	14	220-390				
1	MASTERS	5	235-405				
2	MONARCH	MINED OUT	MINED OUT				
2	CARNEY	15-16	120-185				
2	MASTERS	5	145-210				
3	MONARCH	13-15	0-30			29-32	20-32
3	CARNEY	16	80-130	20-35	20-32		
3	MASTERS	5	106-176				
4	MONARCH	13-15	0-30			29-32	20-32
4	CARNEY	16-17	130-370	20-35	20-32		
4	MASTERS	5	156-417				
5	CARNEY	16-17	70-260	3-50WP	0-36		
5	MASTERS	5	93-289				
6	CARNEY	17-18+	70-345	3-50WP	0-36		
6	MASTERS	5	97-373				
7	CARNEY	8 -15	40-105				
7	MASTERS	5	58-160				
8	CARNEY	13-16+	30-225				
8	MASTERS	5	53-256				
9 EAST	CARNEY	6-16	100-220	12-13WP	0-12	7.5-9WP	0-3.5
9 EAST	MASTERS	6	126-256	6.5-7WP	0-3.5		
9 WEST	U CARNEY	4-8	80-220	17.5-18	16.5		
9 WEST	L CARNEY	5-8	85-231			12.5	2.5-4
9 WEST	MASTERS	6	100-259	10-11	2.5-4		
10 EAST	CARNEY	4 - 16	60-240	20WP	0-1.5		
10 EAST	MASTERS	6	74-286				
10 WEST	U CARNEY	4-8	120-200				
10 WEST	L CARNEY	4	125-211				
10 WEST	MASTERS	6	139-245				
11	U CARNEY	3-6	20-160	22-30 WP	0-10		
11	L CARNEY	4-8+	25-172			12	2.5-3.5
11	MASTERS	6	49-210	10-11	2.5-3.5		
12	U CARNEY	4	20-200	8-21WP	0-9		
12	L CARNEY	8-10	25-208			0-16WP	0-3
12	MASTERS	>6-12+	53-248	7.5-10WP	0-3		
13	DIETZ	0-8.5	0-25				
13	MONARCH	0-20	0-40				
13	U CARNEY	4	15-80				
13	L CARNEY	9	21-114				
13	MASTERS	6-14+	50-143				
14	DIETZ	8	0-6				
14	MONARCH	20	16-22				
14	U CARNEY	4	120-150				
14	L CARNEY	9	146-180				
14	MASTERS	5	175-209				

15	U CARNEY	4	100-180				
15	L CARNEY	9	128-214				
15	MASTERS	4	147-253				
16	MONARCH	0-15	0-3				
16	U CARNEY	4-6	40-100				
16	L CARNEY	8-9	47-136				
16	MASTERS	6	65-185				
17	MONARCH	0-17	0-89	30-39WP	0-5.5		
17	U CARNEY	2-5	20-160				
17	L CARNEY	8-9	31-193				
17	MASTERS	4-6	64-237				
18	U CARNEY	0-4	15-45				
18	L CARNEY	2-6	15-61				
18	MASTERS	5	37-97				
19	U CARNEY	4-6	20-60				
19	L CARNEY	2-8	24-76				
19	MASTERS	5	56-124				
20	MONARCH	0-7	0-32				
20	U CARNEY	2-5	20-60				
20	L CARNEY	2-7	22-74				
20	MASTERS	5	54-111				

Notes: WP = where present, as much of the sandstone exists as lenses of varying thicknesses and may not show up in the entire block. Blocks 1, 2, 7, 8, 10 west, 13-16, and 18-20 have no sandstone. In Blocks 3 and 4, the sandstone is present as a thick bed of sandstone. This sandstone thickens towards the south and is thickest south of the blocks and is present as roof of the Carney and floor of the Monarch. In Blocks 5 and 6, the sandstone is thickest in the middle and thins north and south. It is closer to the Carney in the south half of the block and becomes further above the Carney towards the north, where it pinches out to become absent. Between Blocks 5 and 6 in Borehole 578409-MST-UB, there exists 4 small sand intervals above the Carney, the first is 3 ft. above and 3 ft. thick, the second is 18 ft. above and is 3 ft. thick. Between this is an unnamed coal bed which is 5 ft. thick at 32 ft. above the Carney. 50 ft. above the Carney is a 14 ft. thick bed and at 74 ft. above is a 2 ft. thick bed. In Block 9 east of the Carney split, the sandstone exists for both floor and roof material for the Carney and roof material for the Masters. In Block 9 west of the split, sandstone is present in various thicknesses as the roof of the upper Carney, floor of the lower Carney, and roof of the Masters. In Block 10, the sandstone is only present in the southern 35 ft. in Section I-I' and thickens to the south. For Blocks 11 and 12, the sandstone is present in various thicknesses where it exists and is found in the roof of the upper Carney, floor of the lower Carney, and roof of the Masters. In Block 17, the sandstone is only present in northwest corner above the Monarch.

ATTACHMENT C

Room and Pillar Design Recommendations Against Surface Subsidence – Proposed Brook Mine, Sheridan, WY

MEA

May 31, 2017

ROOM AND PILLAR DESIGN RECOMMENDATIONS AGAINST SURFACE SUBSIDENCE – PROPOSED BROOK MINE, SHERIDAN, WY

1. ROOF ENTRY FAILURE ANALYSIS

    a. Stoping potential should be evaluated by an accepted equation for the room (entry) and pillar configuration with parameter values representative of the cave-in material.

    b. If stoping height exceeds the ground surface from 1.a., assess whether a rock bed of sufficient strength, thickness, and durability exists to bridge the underlying upward propagation of the cave over the long term. Bed should be at least 2 ft. thick.

    c. If there is no “bridging” overburden rock bed, reduce extraction height and/or width until the potential stoping height is less than the mine depth.

    d. Where there are vertically stacked entries, perform surface subsidence evaluation similar to the above, but consider cumulative extracted height with mine depth of the lowest mined seam where no “bridging” bed is present above in the overburden.

2. PILLAR FAILURE ANALYSIS

    a. Determine vertical pressure on pillars. Account for arching pressures which may be present from varying pillar width and stacking of pillars from multi-seam mining and changing overburden depth.

    b. Determine the maximum extraction height of the coal seam and range in pillar widths for mining under consideration. Appropriately reduce the pillar width which would be affected by the softening/deterioration of any clay parting.

c. Based on testing, determine the appropriate overall large scale cube strength of the seam to be mined. Appropriately reduce the coal strength for any clay partings based on thickness and long term strength of the parting(s).

d. Utilize the Mark-Bieniawski equation to determine the pillar strength assuming the coal strength determined in 2.c.

e. Use appropriate stability factor (or safety factor) for long term stability to determine minimum pillar dimension against failure from outright crushing.

3. ROOF/FLOOR BEARING FAILURE ANALYSIS

a. Delineate roof and floor extending to two times the width of the immediate pillar into durable and non-durable layers using appropriate slake durability testing and classification. Areas of core recovery losses should be considered non-durable rock.

b. Where the rock is appropriately classified as durable to two times the width of the immediate pillar (i.e. potential shearing zone), that roof or floor is considered durable. Where the vast majority of the rocks classify as non-durable over this distance from the pillar, the roof and/or floor is considered non-durable. Where potential shearing zone contains significant amount of non-durable and durable materials, the bearing state is considered mixed.

c. Because the thickness of a specific non-durable zone can play a key role in the bearing strength of the roof or floor, the thickness should be assumed at the value unlikely to be exceeded. A durable rock zone should not be assumed if it is less than 2 ft. in thickness in any location in the area under consideration.

d. For durable roofs or floors:

   i. The average rock strength is determined by an ample number of representative tests which appropriately measure uniaxial compressive strength (averaging assumes reasonable tested strength variation).

   ii. The average rock mass strength is then determined by appropriately considering the degree of fracturing in the rock.

   iii. Utilizing the classical bearing capacity formula for foundations resting on uniform cohesive medium, the ultimate pillar bearing pressure is determined for the roof and floor using the pillar plan dimensions. The cohesion strength of the bearing zone is taken as one half the average rock mass uniaxial compressive strength determined in 3.c.ii.

   iv. The minimum sized pillar is determined for the long term assuming sufficient data has been collected, for the durable roof or floor zone by considering a safety factor of 3 and a pillar pressure based on 2.a.

e. For non-durable roofs or floors:

   i. The strength of the non-durable rock must be considered over the short and long term as these rocks by definition deteriorate over time. In the short term, the average, representative compressive strength of the fresh rock at its natural moisture should be determined from an ample number of tests throughout the potential shearing zone. For the long term strength, the non-durable rock will revert to a soil-like consistency and thus drained friction and cohesion values representative of this state should be established from adequate testing of the specific stratum under consideration.

   ii. For short term roof or floor bearing, these fresh non-durable rocks (unexposed to groundwater) should behave more as a rock and consequently rock fracturing should be appropriately accounted for in determining the rock mass strength. Obviously, in the long term, the effect of rock fracturing can be discounted as the non-durable rock will be soil-like.

iii. For a reasonably uniform non-durable in the potential shearing zone, the classical bearing capacity formula for foundations resting on a uniform medium can be used to determine the ultimate bearing pressure for the roof and floor and the plan pillar dimensions. The cohesion strength of the bearing zone is taken as one-half the average rock mass strength determined in 3.e.ii. In the long term, the same equation can be used to determine the ultimate bearing capacity.

Where two distinct non-durable zones with different strengths are present, utilize the appropriate foundation bearing relationship for this condition in either the short or long term.

iv. The minimum sized pillars are determined, assuming sufficient data has been collected, by considering a safety factor of 3 for the roof, 3 in the short term, and 2 in the long term for the floor.

f. For durable rock over non-durable rock, or non-durable over durable rock:

i. Representative strengths of distinct durable and non-durable zones within the potential shearing zone are determined as respectively given above.

ii. The ultimate bearing roof or floor capacity should be determined by appropriate relationship which represents the non-durable and durable conditions present.

iii. Both short term and long term safety factors should be determined to establish the minimum acceptable pillar width. For roof condition, the short and long term safety factor should be 3. For the floor, a factor of safety of 2.0 should be used for all cases.

4. The above recommendations assume that no significant engineering geological features are present, and that a sufficient number of borings were performed, to where it is unlikely that more adverse ground conditions remain unknown.