Application of Ground Penetrating Radar (GPR)
at the
Cryo-Genie Gem Pegmatite Mine, San Diego County, California

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Discovery of a major gem tourmaline pocket at the Cryo-Genie Pegmatite Mine, San Diego County, in September, 2001, prompted the author to suggest to the mine owner that Ground Penetrating Radar (**GPR**) might be a useful tool to assist in the exploration efforts at the mine, (Kampf, et.al., 2003, Figure 1). Previous investigations at other San Diego County gem pegmatite mines demonstrated the efficacy of GPR for delineating pegmatite orientation and finding gem pockets, (Patterson, 1996, Patterson & Cook, 1999, 2002). However, not all gem pegmatites are amenable to the use of **GPR**, (Lees, pc, 2003). High clay contents in the overburden and wet clay seams within a dyke limits the depth of penetration and reduces the **GPR** signal quality. Poor understanding of the mineralization sequence and internal structure of a pegmatite hampers interpretation. Therefore, this study was undertaken to establish whether **GPR** would be as effective a geophysical exploration tool at the Cryo-Genie Pegmatite Mine as it has been at other San Diego County mines.

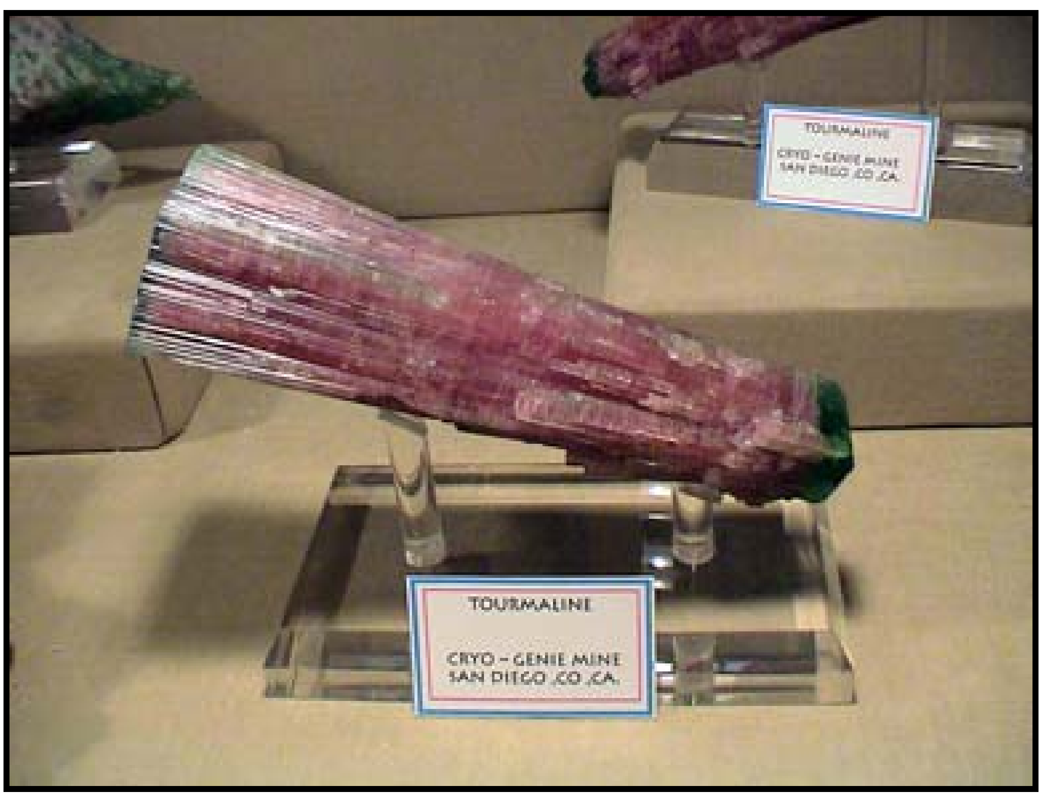

Figure 1: Gemmy Elbaite Tourmaline from the Big Monday Pocket, Cryo-Genie Mine. (Gochenour's Minerals showcase, Mineral Society of Southern California Show, December, 2001)

The Cryo-Genie Mine is located in northern San Diego County, about 2 miles North-Northwest of the village of Warner Springs, (*Agua Caliente*), (Figure 2). The locale was mentioned in the first geologic investigation of San Diego County by Blake, as part of the railroad surveys near the 32nd parallel, (Parke, 1854-1855). Blake reports lithia mica in the sediments of the canyon near *Agua Caliente*, (Figure 4). This particular site was first prospected as the Lost Valley Truck Trail Prospect in 1904 for gem tourmaline and beryl by Bert Simmons with little success, (Gochenour, 2002). The claim was located as the Lindy B Mine by the San Diego Mineral and Gem Society in 1962 and as the Cryo-Genie in 1974 by Bart Cannon. Since 1994, Dana Gochenour has held the claim to the mine. A complete history of the current mining operations and mineralogy is given in Kampf, et.al., (2003), and at the Cryo-Genie Website at: (http://home.earthlink.net/~goke/Cryo-Genie.htm). A mining diary of activities in 2002 can also be found on the MSA Pegmatite Interest Group website at:
(http://www.minsocam.org/MSA/Special/Pig/PIG_articles/PIG_articles.html).

Figure 2: Site Location Map

Basic information on the geology and mineralogy of the pegmatite is available in Weber, (1963, p. 106). He describes the location, geology, and mineralization as follows:

" Deposit consists of a granite pegmatite dike, enclosed in hybrid rocks, which is exposed just southwest of the crest of a small hill. The dike strikes northward, dips about 30 degrees to the east, is about 10 ft. thick, and can be traced laterally for about 200 ft. The dike can be divided into 3 zones: (1) a lower zone, about 4 to 5 feet thick, which is chiefly graphic granite; (2) a core, about 1 ft. thick, which is composed of quartz, albite (including variety Clevelandite), muscovite, lepidolite, tourmaline, garnet, and allanite; and (3) an upper zone, 4 to 5 ft. thick, which is medium to coarse grained graphic granite with muscovite and black tourmaline crystals as long as 9 in. The tourmaline crystals of the core commonly range in color from solid black to crystals with black cores and grass green exteriors. Also noted were pale blue, pale pink, and colorless crystals. Pale crystals are thin and probably average less than ½ to 1 in. in length. Some of the smallest crystals are gemmy". (Figure 3)

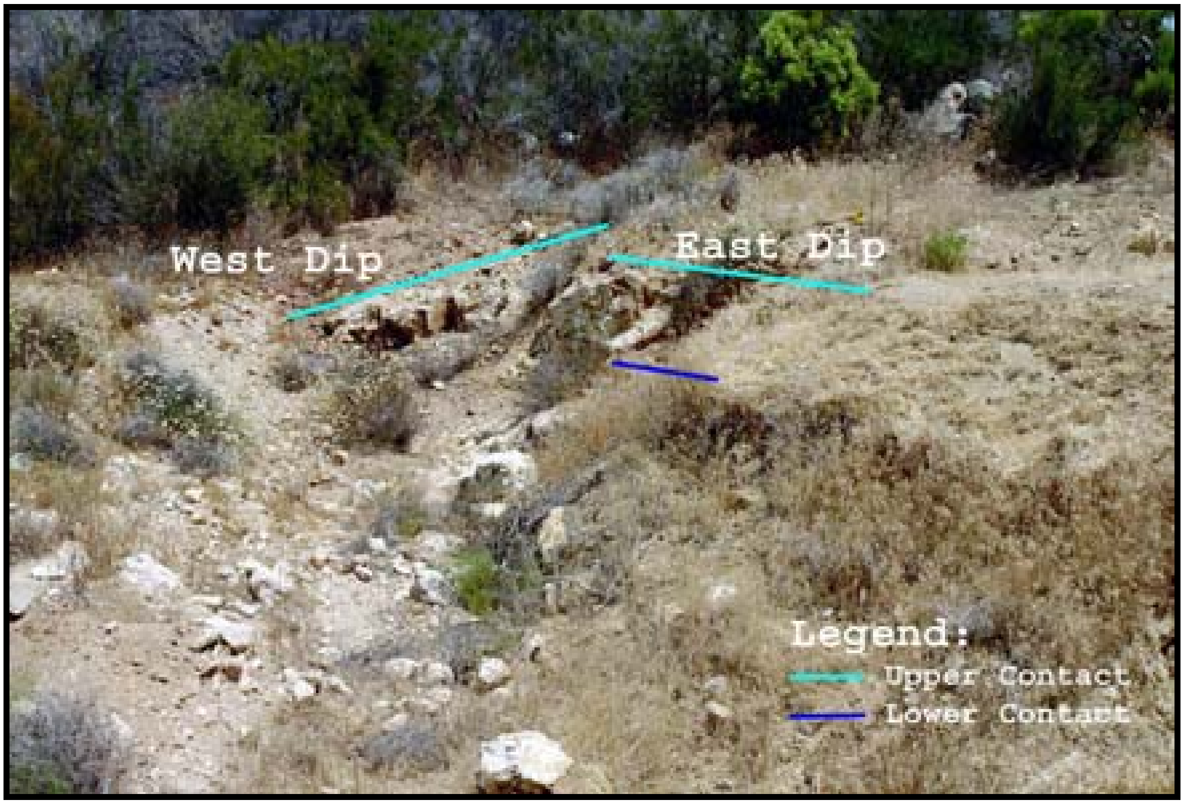

Figure 3: Outcrop southwest of crest of small hill. The dyke strikes north and dips both west and east. Green and Pink Elbaite Tourmaline and Morganite Beryl were recovered from this section of Dyke 2.

During October, 2001, the author visited the site to conduct a geological reconnaissance of the underground workings with a lighted display of the First Pocket, a major Quartz and Lepidolite zone. We also wanted to review the general geology as presented during a Smithsonian Museum Pegmatite Camp, June, 1997, because in 1997, the site was overgrown with brush and only small typical Orthoclase, Quartz, Muscovite, and Schorl blocks were visible on the dump of Dyke 1. Dyke 1, containing the primary mine workings, generally strikes North, dipping 26 to 36 degrees to the West. Underground, in the recently excavated stopes, the dip is West 36º. In the region of the current working face, File 104, the dip is West 26º. A typical surface exposure of Dyke 1 is shown in Figure 5. For the most part, the dyke resembles the other classic LCT, (Černý, 1982), pegmatites of San Diego County. But, there are significant differences that make the Cryo-Genie pegmatite unique. These differences will be discussed below. Two other dykes outcrop on the claim. Dyke 2 has been mined, in the southwest outcrop, for gem tourmaline and morganite. Dyke 3 has only been exposed in a small glory hole and appears to be barren.

The preliminary investigation of Dyke 1 was conducted on 6 January, 2002. Data were collected with a GSSI SIR-4400R **GPR** unit and recorded on a model SR-8100H Graphic Recorder, (Figure 7). The antenna used was a GSSI Model 3105, operating at a central frequency of 300 MHz, (Figure 6). This equipment was manufactured in 1984 and uses Intel-286 processor technology. Hardcopy, analogue, output is available on heat sensitive carbon paper. The Model SIR-4400R has limited data acquisition capability, being used originally for the identification of very near surface, (10 to 50 cm), concrete reinforcing rods and conduit. The maximum scan range is 400 ns. No digital signal enhancement is available on this early model. The mode of recording was ‘continuous’ for all scans.

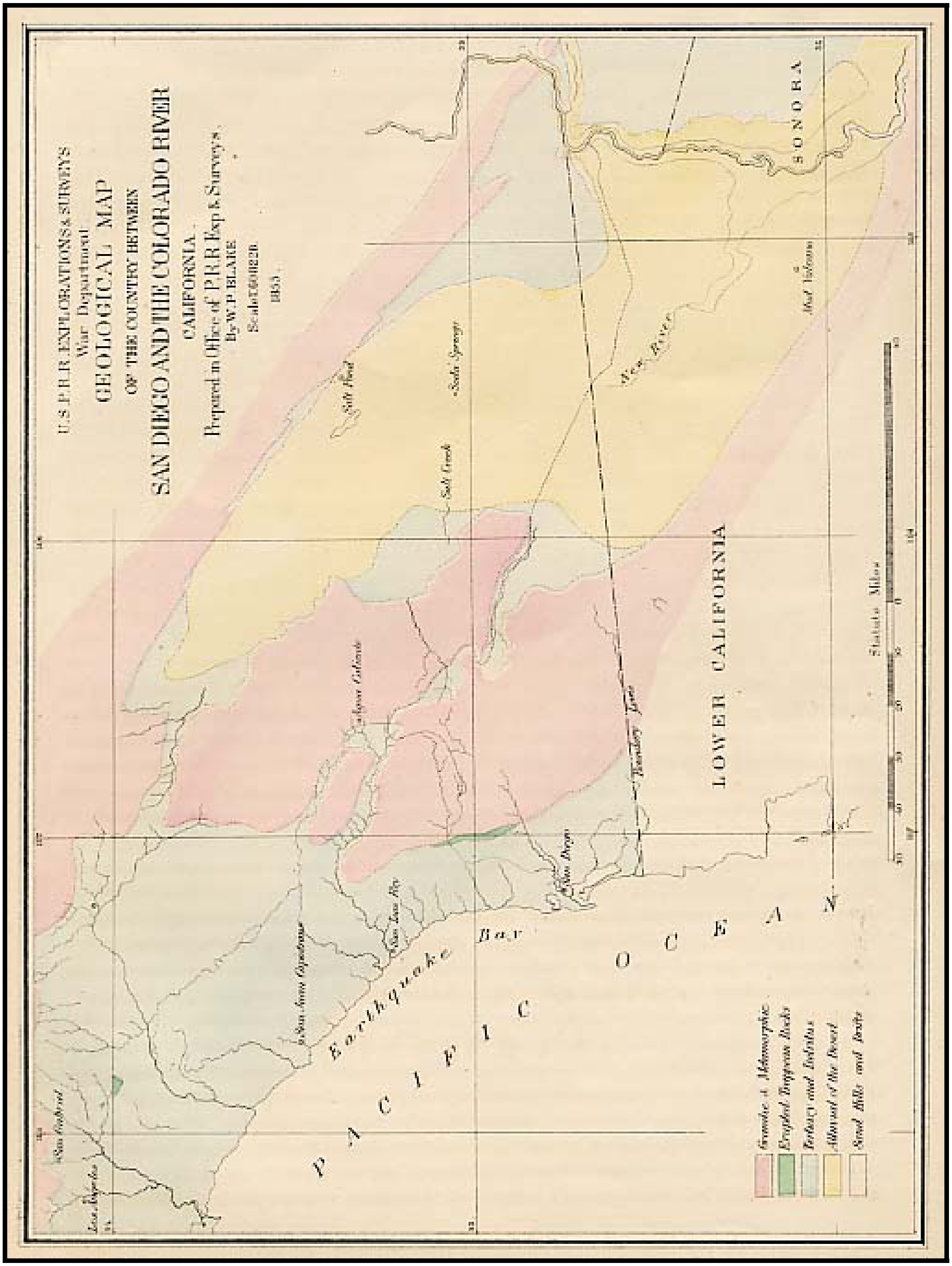

Figure 4: First geologic map of San Diego County.

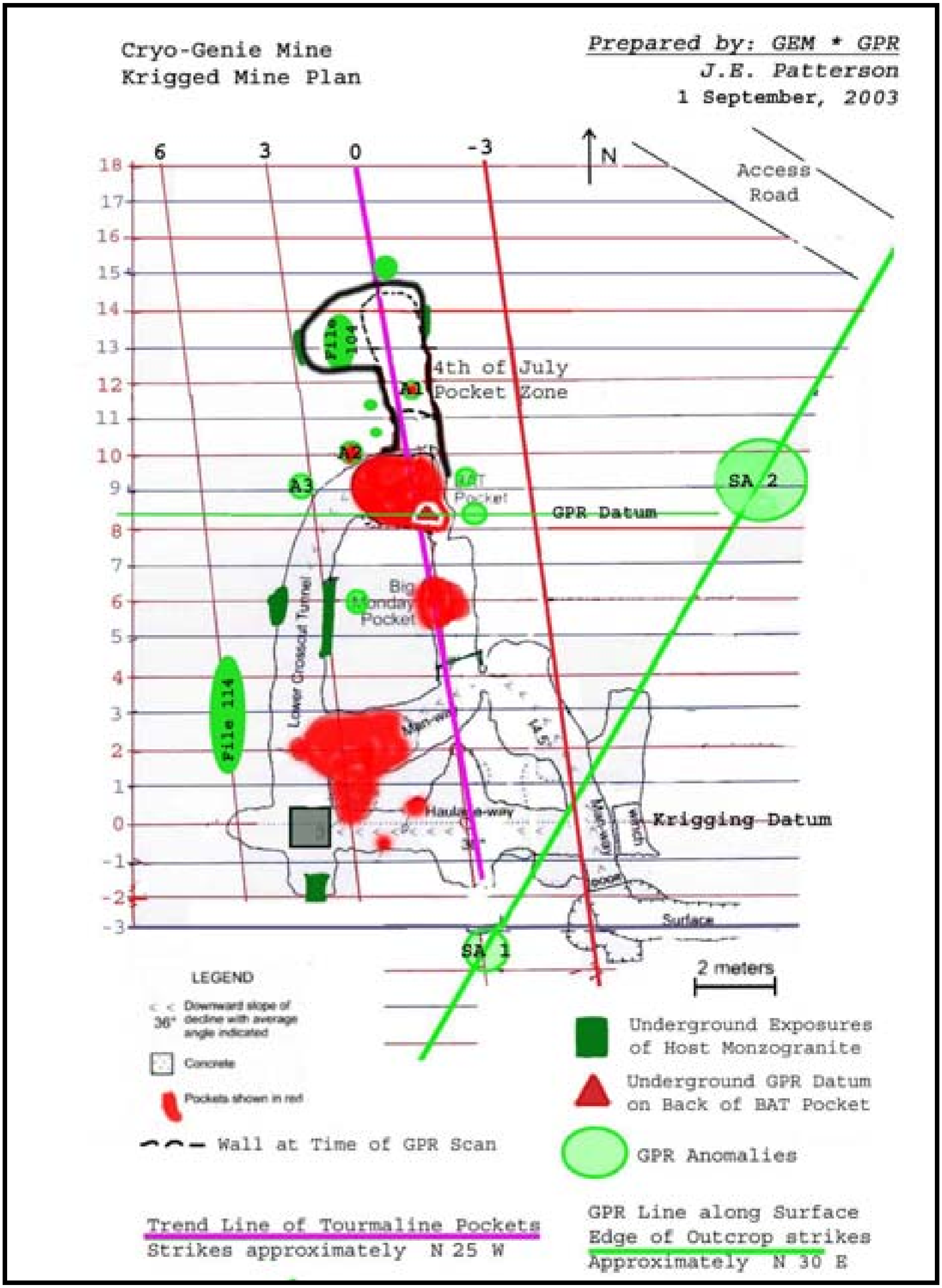

Figure 5: Sketch plan of the Cryo-Genie Pegmatite Mine showing areas of **GPR** Scans on **Dyke 1**.

For the purposes of the preliminary investigation, the 300MHz, central frequency, broadband antenna was selected to provide a reasonable image of the near surface region, (less than 5 m). No underground scans were attempted at that time due to the noxious fumes generated by the heat sensitive carbon paper output. A/C power, 110 volt, for the graphic recorder was provided by the on-site electric generator. This limited the area to be scanned by the length of available power cords. The SIR-4400R **GPR** is powered by a 12 volt gel-cell motorcycle battery and has an operating time of about 4 hours. The combined weight of both units is over 40 kg, so the equipment was transported in the bed of a 4x4 truck, (Figures 6 & 7).

Figure 6: Outcrop of the pegmatite, northeast of the current underground workings. Dyke 1 is west dipping and approximately 1 meter in thickness at this point. The 300 MHz antenna is to the left front of the truck.

Figure 7: GSSI Model 4400R **GPR** unit and Model SR-8100H Graphic Recorder. The **GPR** unit is powered by a 12 volt D/C gel-cell battery. The Graphic Recorder is powered by 110 volts A/C.

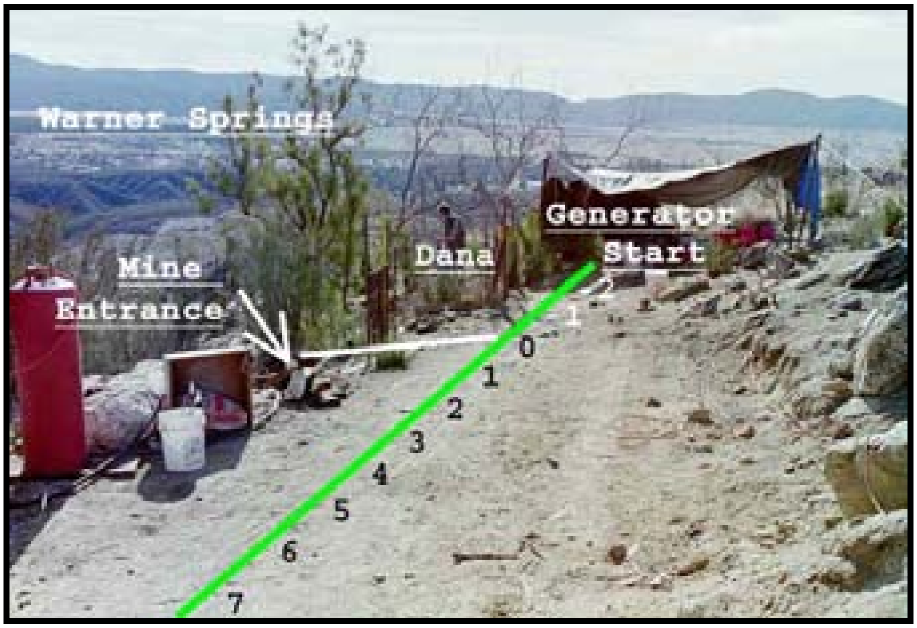

Figure 8: Outcrop of the preliminary investigation scan line area of Dyke 1, looking southwest.

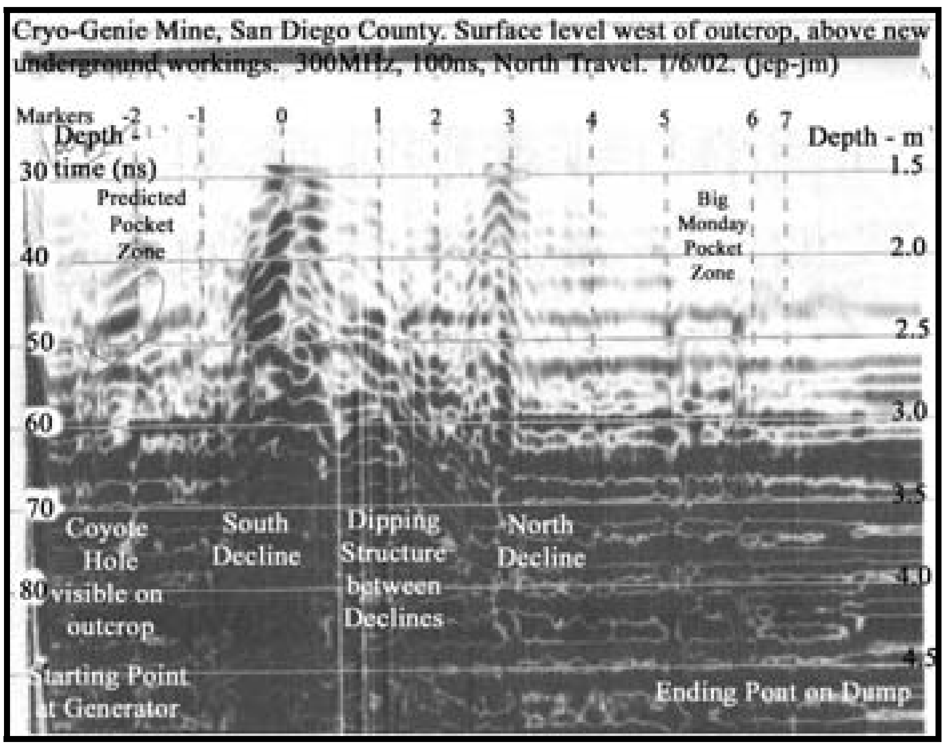

Figure 9: Interpreted Scan 1 on Dyke 1. Compare with Figures 5 & 8.

During the surface survey of Dyke 1, marking flags were positioned every 1 m along the route of scan. These line of scan marks are shown on Figure 8 as vertical dashed lines. Correlation of the flags - marks with the known position of the underground workings is very close, giving strong support to the interpretation. The results of **GPR** scan line 1 are shown in Figure 9.

Interpretation of the **GPR** output shows that there are several discernable features on the scan. A previously excavated surface cavity, or 'coyote hole', is clearly shown at mark **-2**. Note that the electrical generator, near this position, has no obvious effect on the recorded signal. A significant tunnel-type anomaly occurs at mark **0**, which matches the measured location of the South Decline. A second tunnel-type anomaly occurs at mark **3**, which matches the measured location of an excavated zone now used for storage. The sloping anomaly between the declines appears to be the return from the fractured pocket zone.

On 16 June 2003 we scanned again, this time underground using only the SIR-4400R **GPR** unit. The transient, single line "oscilloscope", output was surprisingly easy to interpret in the darkness of the drift, even without automatic gain control, (Figure 10). We were able to discern three small anomalies as follows: **A1)** on the face of the working drift, was excavated and found to be the 4th of July Pocket, containing a nice bi-colored gem tourmaline, an etched blocky pale purple aquamarine, and a large, 25 cm quartz crystal; **A2)** on the wall between the main drift and the BAT Pocket area, was excavated and found to contain a small gemmy thumbnail sized tourmaline; **A3)** along the wall of the main drift has yet to be excavated. This gave us another successful trial, so decided to upgrade our equipment to a proper, military hardened, GSSI SIR-II **GPR** unit, with digital storage and data processing capability, (Figure 11).

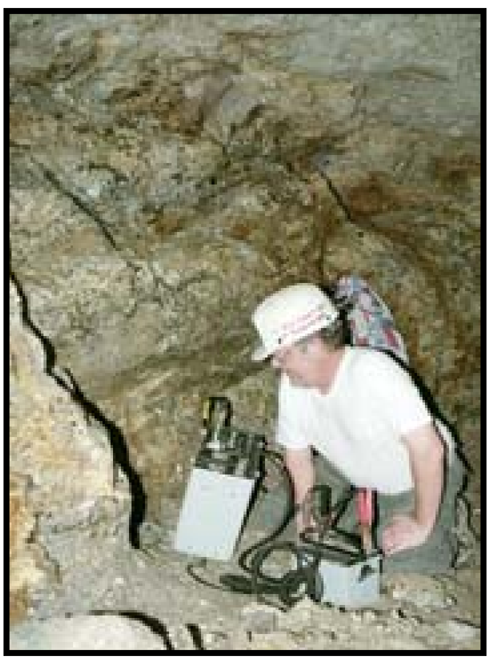

Figure 10: The Author reads the visual output from the GSSI SIR-4400R, excavated BAT Pocket area, view S 40 E.
Figure 11: GSSI SIR-II **GPR** & 900 MHz antenna, northwest corner of excavated BAT Pocket area, view N 40 W.

To test this new unit, we chose the cleared and leveled staging zone overlying the southwest surface workings, (Figures 3 & 12). The scan of Dyke 2, File 53, was conducted 13 July, 2003. This scan was aligned along an apparent dip of Dyke 2, from South to North. The time-depth recording of this scan was set to 100 ns, which provided an interpretable resolution at the maximum target depth of 5 m. The interpreted line of scan 2, File 53, is shown on Figure 13.

In order to correlate and verify our Cryo-Genie interpretation, we returned to our previous work at the Little 3 Mine, Ramona, (Patterson, 1996). This is a similar tabular LCT pegmatite with a dip of 32º. Figures 14, 15, and 16 from the Little 3, show the line of scan, the excavated line of scan, and the interpreted **GPR** scan. The similarities between the Cryo-Genie and Little 3 dykes are very clear. Based on these similarities in the scans, we proceeded to conduct the underground survey at the Cryo-Genie as described below.

Figure 12: Southwest outcrop zone showing the line of scan for Dyke 2, File 53, looking southwest.

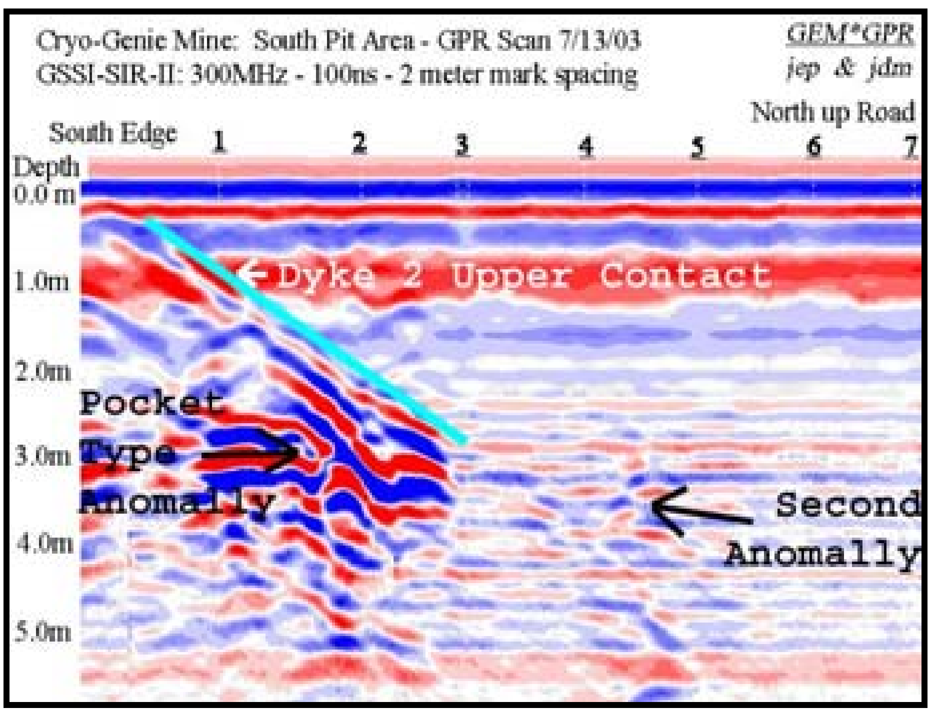

Figure 13: Interpreted Scan Line 2, File 53. The dipping dyke structure is clearly visible. A potential pocket zone anomaly appears near marker 2 at about 3.0m depth. A second anomaly zone appears between markers 4 & 5 at about 4.5m depth. This second anomaly could be a pocket zone or the intersection with another dyke. Compare with figure 12.

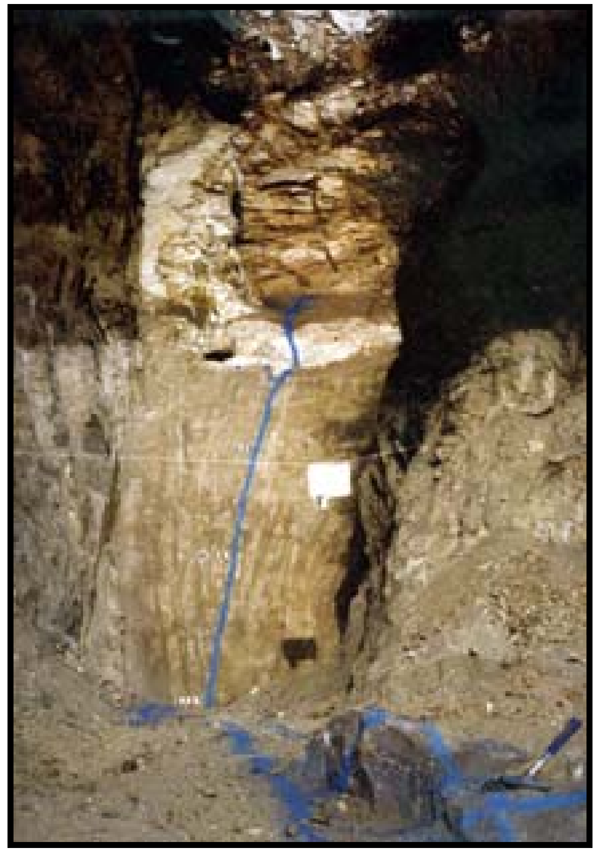

Figure 14: The GPR Line of Scan from our original work at the Little 3 in 1996.
Figure 15: The excavated area from Figure 14, with GPR line of scan painted in.

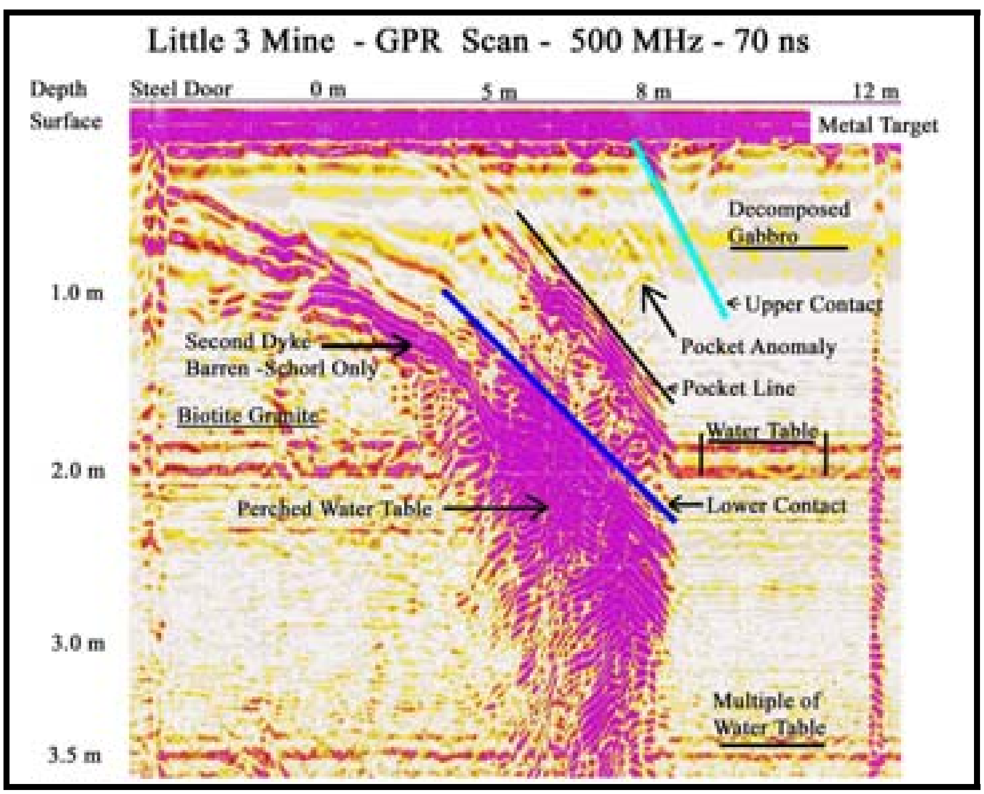

Figure 16: Interpreted GPR scan from the Little 3 Mine. Compare with Figures 13, 14 & 15.

Our next challenge was to scan the underground workings with the SIR-II **GPR**, to determine if we could identify any pocket anomalies. Since correct geophysical interpretation requires a superb understanding of the structural geology as well as mineralogy of a pegmatite system, we started with a detailed review of the structure of the dyke as observed in the underground excavations. The dyke dilates from about 1 meter at the surface outcrop near the mine entrance and as shown on Figure 6, to about 2.5 meters at the zone of pockets shown on Figures 5, 19 to 23, 29 to 32, and 36 to 38.

The following geologic description is preliminary, due to the limited exposures available in the current surface and underground workings. Since each LCT pegmatite has its own unique fingerprint, based on the slight differences in initial melt composition, melt volume, pressure at the time of intrusion, and subsequent cooling and crystallization, continued mining will allow for additional further investigation and clarification of interpretation. The Cryo-Genie offers a rare opportunity to study this type of gem bearing pegmatite as mining progresses. Already unique rare minerals such as Löllingite, Bismuthinite, and Pääkkönenite have been identified and described, (Kampf, et.al, 2003).

A cross-section for typical barren zones is shown in Figures 19 and 20. The upper contact of the pegmatite, with the overlying Quartz–Biotite gneiss and monzogranite, consists of a Biotite rich Quartz–Oligoclase border for about 5 cm. The a-axis of the Biotite is normal to the contact. This grades rapidly into a massive Orthoclase, Quartz, Muscovite, and downwardly flaring Schorl unit for about 1 m, (Figures 19, 20, 29, and 30). In places there are horses, (xenolithic inliers), of the overlying gneiss and monzogranite, pods of quartz with the a-axis of muscovite parallel to the contact, 1 to 3 mm almandine garnets, sparse nodules of hydrothermally altered Mn,Fe Phosphates, and pods of granitic textured pegmatite, (Figures 29 to 32). Near the middle of the dyke, the Schorl crystals may start flaring upwards and Lepidolite may appear in interstitial feldspar zones, (Figures 20, 24, and 30). Beneath this central zone is a single, prominent, undulating band of aplitic grained Garnet, Schorl, Quartz, Albite, and Muscovite. Additional coarse bands of rough textured pegmatite constitute the next zone for about 75 cm. The lower contact zone, exemplified by the outcrop near the bottom of the haulage-way, is characterized by dark brown Mn,Fe phosphate stained, typical pegmatite minerals having a granular texture, with a sharp contact with the host gneiss – granite, (Figure 19).

In the pocket regions, (First Quartz, Big Monday, BAT, and 4th of July), things change significantly, with the perthitic Orthoclase changing to perthitic Microcline in which the plagioclase has been leached out and re-crystallized elsewhere as Clevelandite roses, (Figure 1). The Potassium Feldspar also changes color from off-white/grey to buff as a pocket zone is approached, (Figures 31 and 36). Within a pocket, the majority of the massive K-Feldspar is fractured along cleavage planes and suspended in an ocher brown sticky mud, (Figure 37).

The pink Elbaite tourmaline, with late stage blue-green caps, does not grow in a fractionated form along the C-axis, as at the Himalaya Mine, rather it grows as free flaring crystals in the open spaces of a pocket, on flat lying interstitial faces of Microcline crystals, or as epitaxial continuations from previously crystallized Schorl terminations, (Figures 1, 17, and 24). The finest pink Elbaite tourmaline specimen found to date is on display in the Hall of Gems and Minerals at the Natural History Museum of Los Angeles County. (http://www.nhm.org/calendar/home.html) , and is featured on the cover of the May/June issue of Rocks and Minerals (Kampf, et.al., 2003) .

In the pocket regions, the central portion of Dyke 1 may dilate an additional 1 meter. However, until complete contact to contact excavations are made, or diamond core drilling is conducted, the exact thickness of the pegmatite will remain unknown. In the region between the BAT Pocket and the current working face, File 104, there is a second pocket zone underneath the aplitic band. This lower pocket region is enriched with lithium and contains small vugs with gemmy blue-green Elbaite tourmaline. Beryl maybe found in both pocket regions of the pegmatite.

Figure 17: Microcline with leached and re-crystallized Albite (Clevelandite), Quartz, and flat lying, gemmy, polychrome Elbaite tourmaline. (BAT Pocket). (Gochenour's Minerals showcase, Mineral Society of Southern California Show, December, 2001)

Figure 18: Perthitic Microcline, completely leached of all plagioclase. This mineral re-crystallizes elsewhere as Clevelandite. An apparent 3rd pulse of microcrystalline pink and green Elbaite tourmaline and laths of Albite cross-cut the leached microcline crystal and then crystallize as euhedral micro-crystals with quartz crystals in the open interstitial zones between microcline blocks.

Figure 19: Barren zone at the south end of the main drift. A horse of the country rock is exposed just above the 117 marking. A downward flaring schorl is exposed just left of the *. The band of Garnet, Schorl, Quartz, Albite, and white Mica is exposed along the lower section. **Figure 20**: Northwest wall of the main drift leading to the BAT Pocket area. Note upwardly flaring Schorl above the banded zone with a small patch of lepidolite above it.

There is no central pocket line in Dyke 1, as typified by the historical drawings in Figure 26 or the photograph of the cross-section of the gem bearing Topaz Ledge at the Little 3 Mine, Ramona, (Figure 28). Nor does the pegmatite fractionate continuously inward from contact to contact, creating oblate spheroid pockets as at the Himalaya Mine, Figure 27. Rather, two primary discrete pulses make up the majority of Dyke 1. An apparent third pulse appears to have brought in the majority of the Lithium, Beryllium, and Boron enriched pocket mineralization. This created an interesting internal texture to many of the Microcline matrix specimens, (Figure 18).

The majority of the pegmatite consists of a first pulse, which appears to be a high temperature Orthoclase, Quartz, Oligoclase, Schorl, and Muscovite phase. Plagioclase, (Oligoclase), is contained within the perthitic microcline and graphic granite of the upper 1 m and portions of the lower sections. Very little, if any, Albite was observed in this upper central zone of the pegmatite. The emplacement of the second pulse brought in a lower temperature Albitic phase and the initial lithium mineralization, as evidenced by graphic Albite-Quartz intergrowths in the bottom of several pockets and the epitaxial rim of Lepidolite on Muscovite, (Figure 22). It also lifted the lower contact into the middle portion of the pegmatite and re-crystallized this biotite border zone to a schorl and garnet rich aplite band. A third pulse appears to have brought in an extremely hydrous salic, lithium, boron, beryllium, phosphate rich melt, that crystallized as the giant Quartz crystals, large polychrome Elbaite tourmalines, (Figures 1, 17, & 18), the massive compact lepidolite masses, and the montebrasite pods, (Figure 25). A post-emplacement, probably Elsinore Shear Zone time, clay filled fracture can generally be followed from pocket to pocket along the current main drift, (Figures 23 and 38).

Figure 21: Downwardly flaring Schorl with a second growth of graphic Quartz - Schorl.
Figure 22: Mn,Fe Phosphate nodule and epitaxial Lepidolite on Muscovite.
Figure 23: Central region of Dyke 1, underground, with upwardly flaring Schorl and a median fracture network. The miners follow this clay filled fracture network between some pockets.

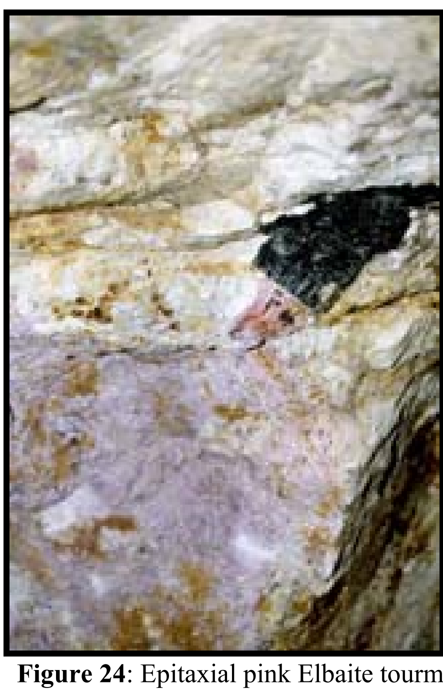

Figure 24: Epitaxial pink Elbaite tourmaline overgrowth on the flat pedion termination of a pulse 1 Schorl crystal.
Figure 25: Montebrasite pod in zone of compact Lepidolite. Main Haulage-way stope, view **N 20 W**.

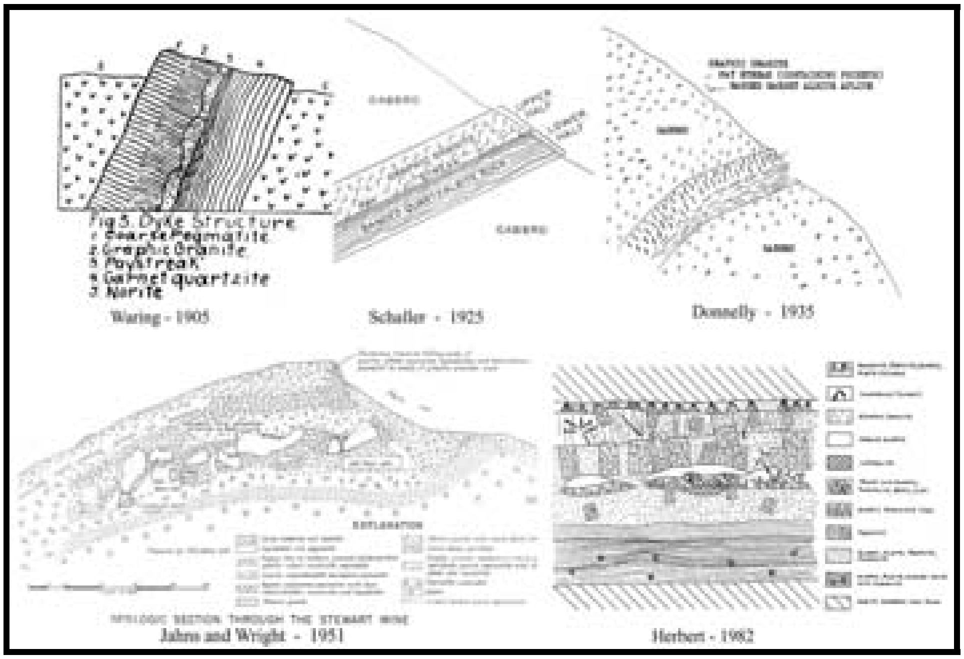

Figure 26: Pegmatite diagrams from various investigators at Pala. Note the simplicity of the early diagrams versus the detail in the later work.

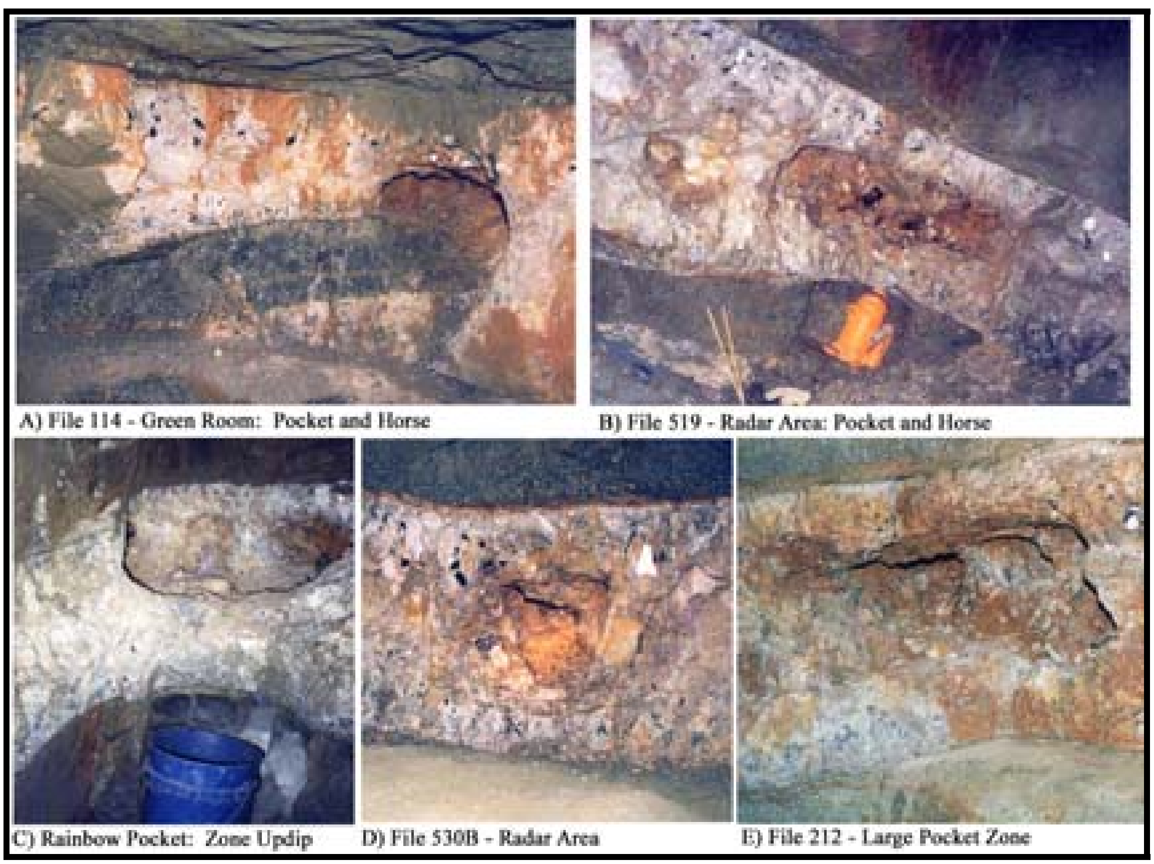

Figure 27: Photographs of pockets investigated during the **GPR** studies at the Himalaya Mine. The Rainbow Pocket in C) was discovered on the 4th of July, 1996. The other pockets were discovered using **GPR** in June & July, 1998.

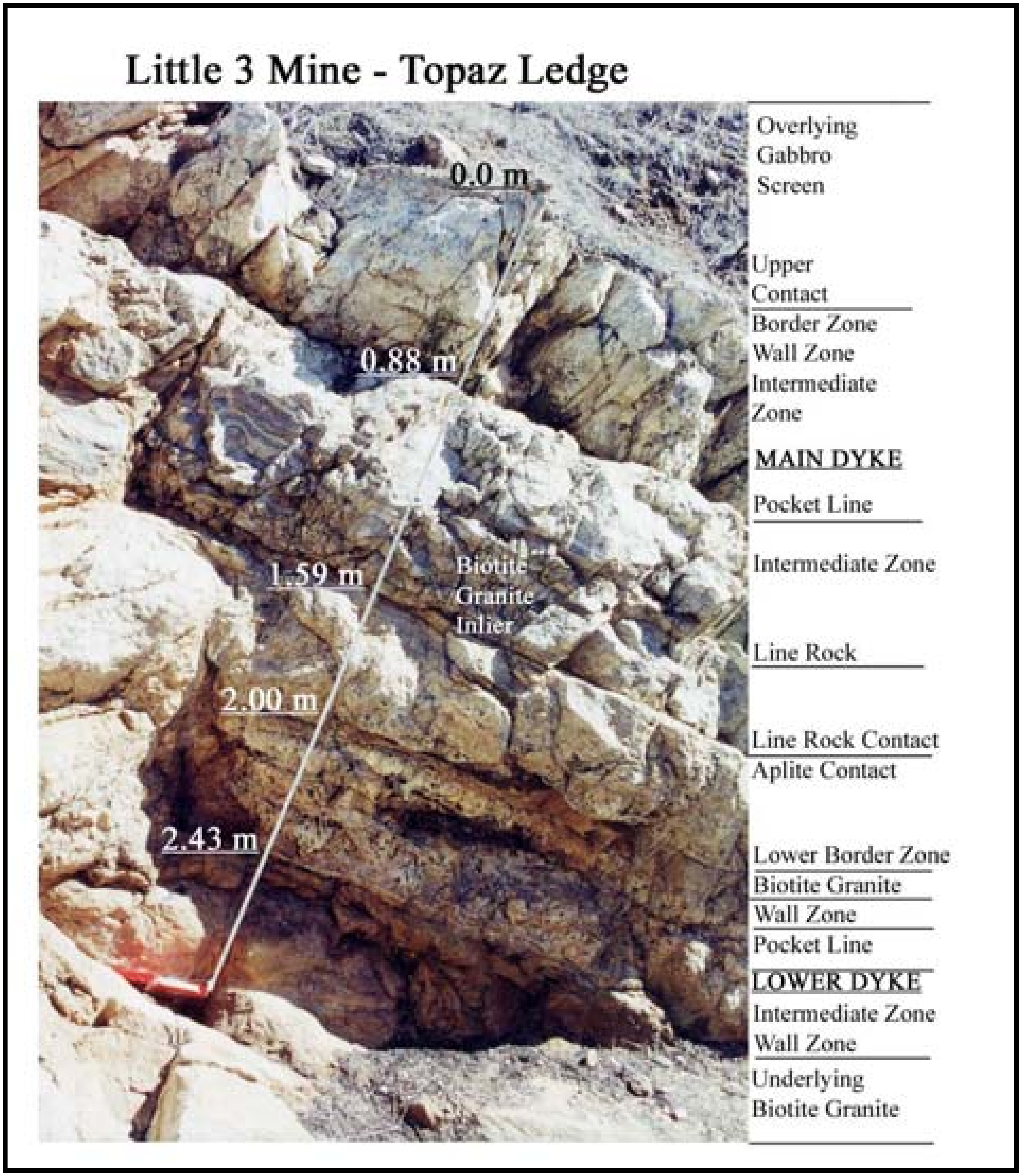

Figure 28: Main Topaz Ledge investigated during the **GPR** studies at the Little 3 Mine, Ramona. This composite dyke consists of an upper Gem bearing dyke with Elbaite, Lepidolite, Topaz, and Hambergite, followed by "Line Rock" with Biotite Granite inliers, an aplitic lower contact, and then another Schorl / Garnet rich lower dyke. It is also the type locality for the rare mineral Boro-Muscovite.

Figure 29: Mine owner, Dana Gochenour, points to zone of potential pocket mineralization, working face **6/6/03**, looking **N 20 W**. **Figure 30**: Same face as Figure 28, washed and cleaned. Note the downward flaring Schorl crystals, the small central pod of Lepidolite in an interstice with Microcline and Albite (Clevelandite), and the aplitic Schorl-Garnet band at the level of the notebook. The Lepidolite mass is considered a good geologic indicator for potential pocket mineralization. Also note the **ocher** staining coating the minerals in the central to lower portion of the photograph. This coating is a distinctive signature of the Cryo-Genie pegmatite.

The underground GPR survey was conducted on 19 July, 2003. The areas previously scanned were re-visited to verify the presence or absence of any noted anomalies. A Datum, marking dots, and start-stop-turnaround lines were painted on the walls and back with bright pink fluorescent spray paint. After each scan, the File number was also sprayed on the wall. For the most part, the GPR surveys are accomplished following industry standard data collection and verification procedures. Each scan line is established, measured, photographed and noted so that the processed data can be positively correlated back to the specific section of pegmatite.

Scanning in the dip direction of a pegmatite presents the most complex condition, as the distance to the upper or lower contact must be considered, and the depth of scan time adjusted accordingly. A nominal 30º dip was assumed for all scans. This gave an approximate distance to the upper contact of 2 meters. The time of the scan, for a dielectric of 8, was set to 30ns. From our experience, this time provides for a 1.5 meter scan depth. Based on our observations and interpretations, no upper or lower contacts were intercepted in any of the scans. Since scanning along the strike of the dyke presents the simplest case. A nominal 30 ns was selected for all underground scans using a 900 MHz, central frequency, broadband antenna.

Figure 31: Working Face, **6/26/03**, view N 20 W. The 4th of July Pocket is exposed in the drill hole at the lower left.
Figure 32: Working face as scanned on **7/26/03**, GPR File 104. Dots indicate marker points. Xs indicated anomalies.

Previously, on 26 June, 2003, we were present in the underground during excavation of the working face of the drift containing anomaly **A1**, (Figure 31). Two lifts were blasted between the faces seen in Figures 29 and 30, and the face shown in Figure 31. Several rare Mn,Fe Phosphate alteration minerals were found in the wall, just above and to the left of the hammer handle. The color of the Potassium Feldspar had changed from grey to buff. Also, the relative location of the Lepidolite mass had dropped downward on the wall face. On the 4th of July, anomaly A1 was opened and found to be a complete pocket, containing a gemmy, doubly terminated, polychrome Elbaite tourmaline, a pale purple mass of Morganite Beryl, and a 30 cm terminated Quartz crystal. The high energy response from this pocket zone may have been caused by the piezeo-electric response from either the Tourmaline, Quartz, or both.

The working face was advanced to the position seen in Figures 5 and 32. The first region to be scanned was the current working face, Files 102 to 109. Since anomaly A1 had been mined through, (Figure 31), we proceeded to scan the extended face of the drift, (Figure 32). For the scan of File 104, at the suggestion of Dave Kalamas, mine security, I directed the antenna downward, towards the downdip continuation of the pocket zone, on the West wall. The antenna direction was adjusted to the mid-level on the North wall and up-dip on the East wall. The raw data results are shown in Figure 33. For this group of scans, the brightest return was observed in File 104, (Figures 32, 34, and 35). A significant angled line was observed in the raw data, (Figure 34), and this was interpreted in real-time as a potential pocket.

Figure 33: Quartz crystal removed from the 4th of July Pocket, with typical pocket wall matrix of Clevelandite, Lepidolite, and blue-green Elbaite tourmaline on upper left. The Quartz crystal is sitting on a typical ocher stained matrix from the floor of the BAT Pocket. This floor matrix consists of small crystalline nodules of Lepidolite cemented in Quartz with a covering of gemmy pink and polychrome Elbaite tourmalines.

The raw data for Files 53, 104, and 114 were printed and presented to Dana Gochenour and Jim Clanin on 29 July, 2003. The nature and location of all the anomalies was discussed with respect to future mining operations. The gemmy tourmaline contents of anomaly **A2** was also verified. The physical condition of the West wall at File 114 was inspected, to rule out the possibility that blast fractures were causing the angled anomalies in the raw data, (Figure 39). The remnant of a shallow single drill hole was found on the surface between markers 2m and 3m, (Figure 38). Further excavation, of File 104, at that time was delayed by the construction of a pneumatically operated hoist system so that the gemmy specimens, pocket materials, and mine muck can be efficiently removed.

Subsequently, the working zone for File 104 was excavated between 4 and 8 August, 2003, (Figure 36). A significant pocket was exposed, as shown in Figure 37. After processing the **GPR** data, (Figure 35), the nature and extent of the near region of the pocket was visualized. In Figure 35, the bright energy regions are interpreted to be Quartz and Tourmaline crystals, sheared free from the walls of the pocket and currently “floating” in a morass of ocher brown sticky clay, small nodules of Lepidolite, and sheared and broken fragments of the pegmatite, primarily Microcline and Quartz. A major matrix specimen of Aquamarine Beryl was recovered from this pocket during the week of 25 August, 2003.

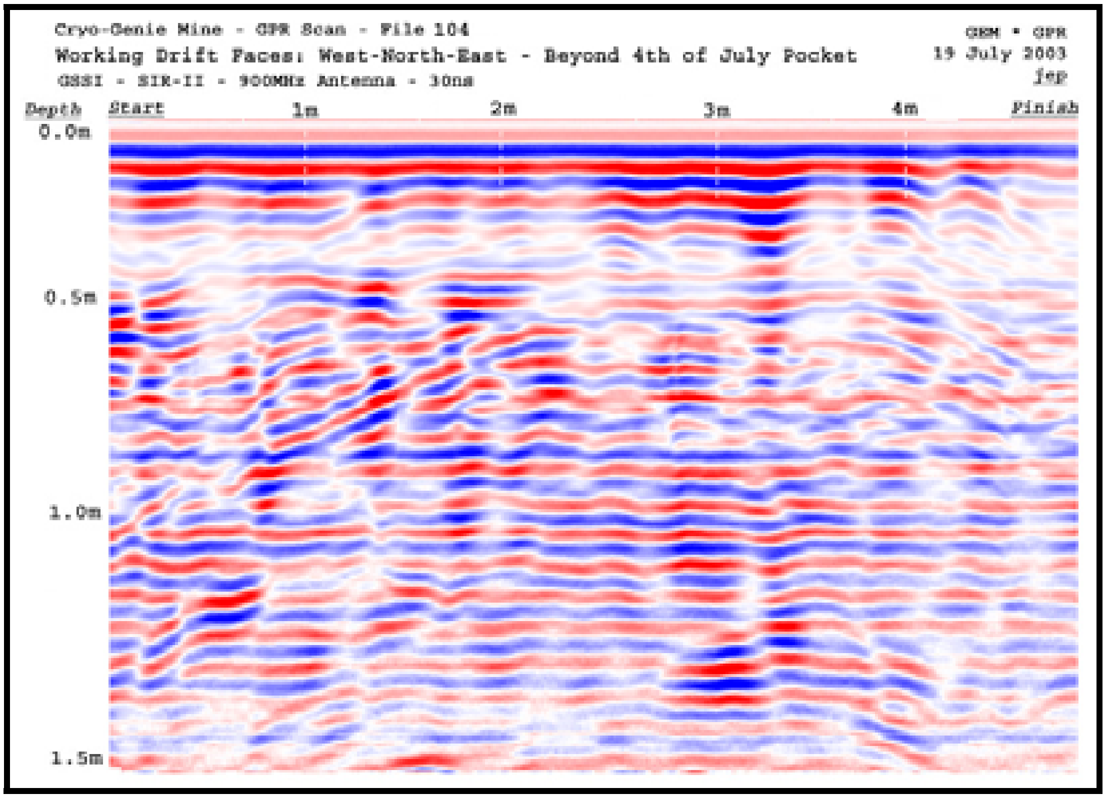

Figure 34: Raw Data **GPR** Scan of the Working Drift, **File 104**. The pocket region is interpreted to lie beneath the sloping line between markers 1m and 2m, and between depths 0.5m and 1.0m. Compare with Figures 29 to 32.

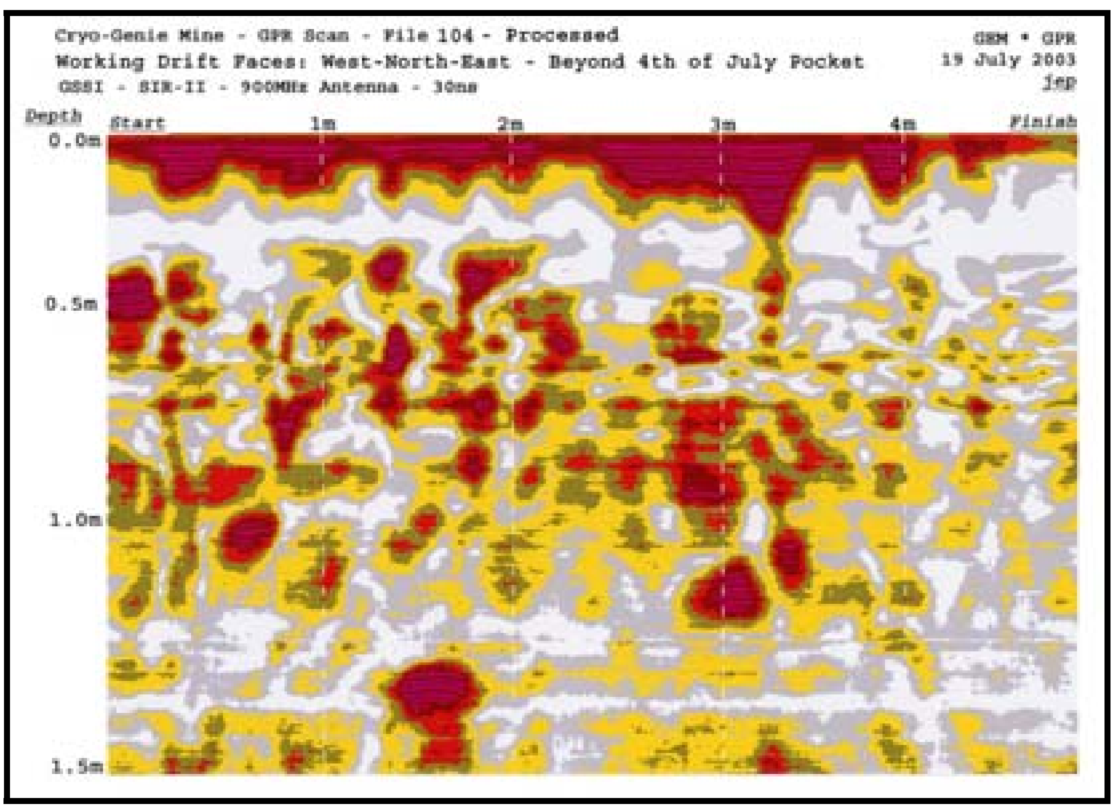

Figure 35: Processed GPR Scan of the Working Drift, **File 104**. The bright energy regions are interpreted to be crystals of Quartz and Tourmaline. Compare with Figures 29 to 32 and 34.

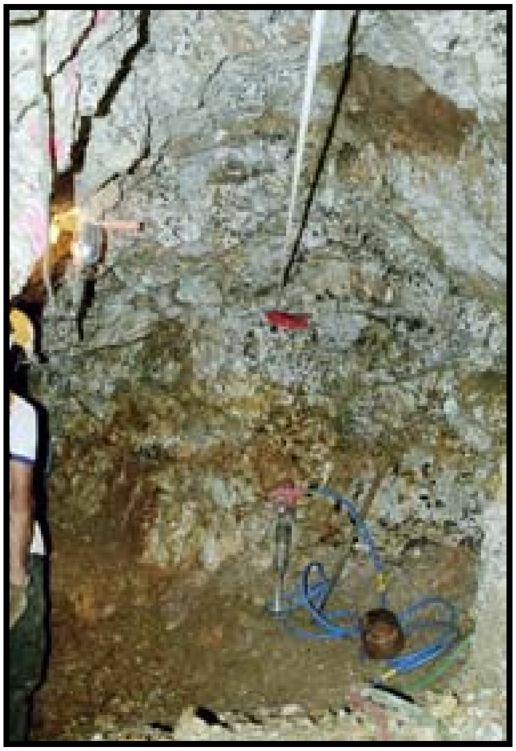

Figure 36: Continuation of the Working face, **N 20 W**. The face of the wall for File 104 has been removed for a distance of about 30 cm. **Figure 37**: Top of Pocket, **File 104**, exposed on **8/8/03**. This zone is shown as the anomalous regions in **File 104** in Figure 23, as the sloping line just before marker 1m and ending just after marker 2m, and as the angled line of bright energy zones between markers 1m and 2m in Figure 24. Additional bright energy zones are now clearly shown between markers 1m and 2m at 1.35m depth, and at marker 3m at 1.15m depth.

Figure 38: The West wall of the main drift, File 114. Anomaly markers are based on a real-time interpretation of the raw data at the time of the scan. Note that there are no clear geologic indicators for potential pocket mineralization along the line of scan. At the 4th of July Pocket zone and at File 104, Lepidolite was evident in the central portion of the pegmatite. This is considered a good geologic indicator at this mine for pockets.

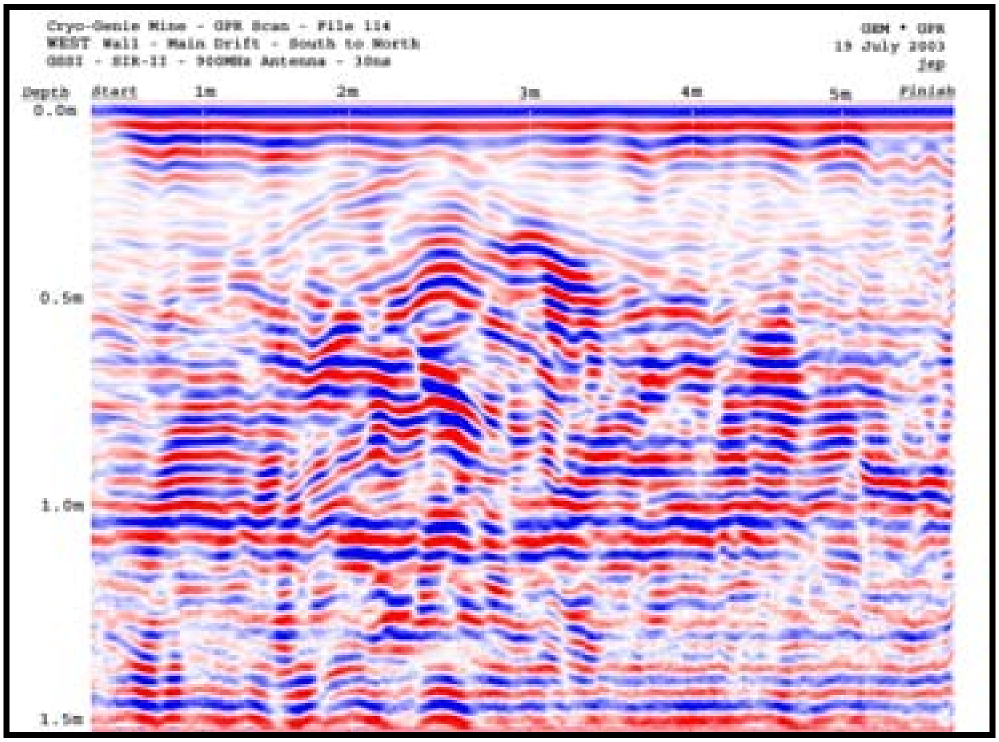

Figure 39: Raw **GPR** data scan for the West wall of the main drift, **File 114**. The bright area between markers 2m and 4m appears to be a major pocket type anomaly. Since the geology of this portion of the pegmatite is not well understood, only a thorough excavation will provide verification of this preliminary interpretation.

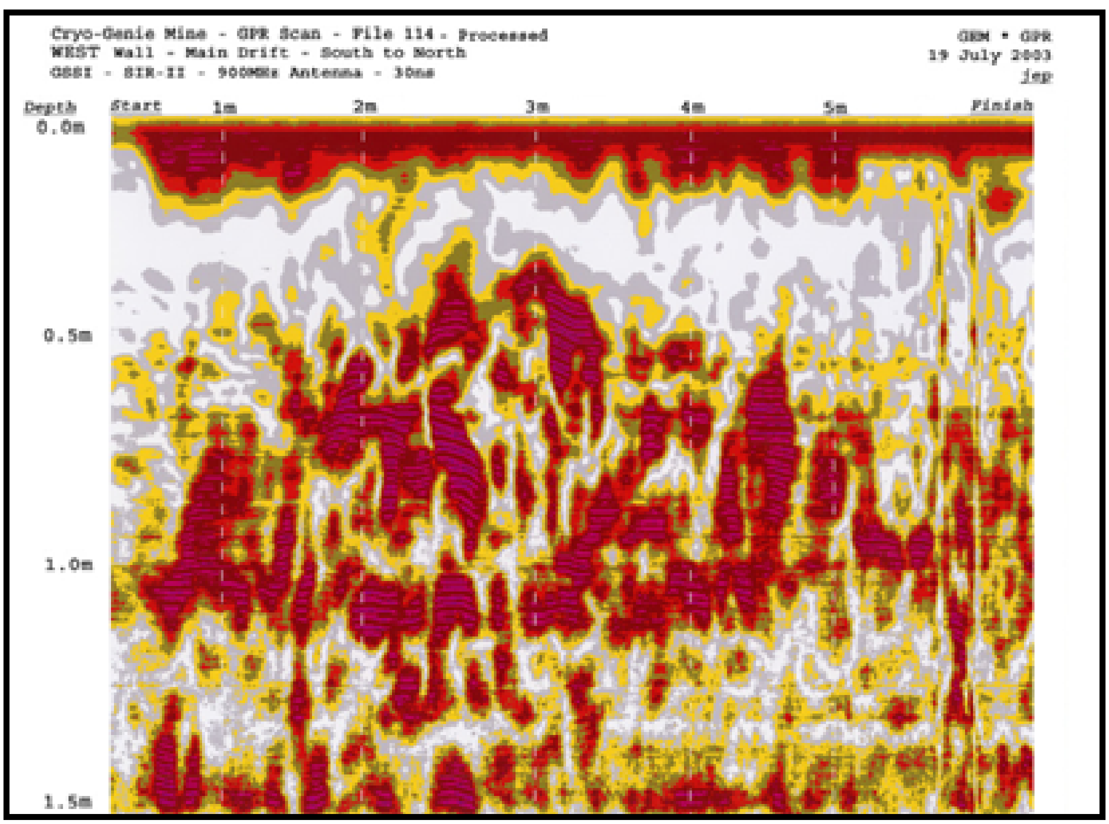

Figure 40: Processed data scan for the West wall of the main drift, **File 114**. The excavation of this anomaly will verify the accuracy of the **GPR** method at the Cryo-Genie Pegmatite Mine

Once the pocket at File 104 is excavated, perhaps attention will be turned to the potential pocket at File 114. According to Dana Gochenour, there is no clear geologic evidence that a potential pocket exists as shown in Figure 38 and interpreted from Figures 39 and 40, especially since the First Quartz Pocket is only 2 meters updip of the interpreted pocket zone, (Figure 5). When both the raw data and interpreted scans of File 104 (Figures 34 and 35) and File 114 (Figures 39 and 40) are compared, the similarity between them is distinct. Our experience at the Himalaya Mine, (Patterson & Cook, 2002), indicates that bright energy returns can be interpreted as potential pockets with reasonable certainty. Barren zones, even if fractured, do not return bright energy. Clay filled fractures generally return linear images as those observed in Figures 13 and 16.

The discovery of pocket mineralization has historically been proven simply by excavating significant portions of a given pegmatite. Certain geological indicators, such as structural changes as seen in rolls and terraces, clay filled fractures between pockets, and solid-frozen pegmatite grading into highly cavernous-vuggy zones, and mineralogical changes such as zoning differences in tourmaline going from Iron rich Schorl to Lithium rich Elbaite, or Muscovite grading to Lepidolite, or color changes in Potassium Feldspar, are all seen as positive indicators of potential pocket bearing sections. Since the trends in the indicators at the Cryo-Genie have yet to be statistically documented, Dana Gochenour and his mine operator, Jim Clannin, have found that their 30+ years of pegmatite mining experience is presently adequate to observe the signs of pocket formation and to follow them to their ultimate productive conclusion. This may be the case with the pocket at File 104. However, until the application of **GPR** for the identification of anomalies associated with pockets, excavation has been the only method of verification.

In this study we have demonstrated that **GPR** can easily identify pocket and structural anomalies within pegmatites. This will aid the mining effort by defining the blast zone before the pocket is excavated, thus reducing costs and minimizing possible damage to the specimens. In sections of the pegmatite where the normal indicators are not present, as at File 114, **GPR** has proven to be invaluable in outlining the face of the pocket region, (Patterson & Cook, 2002). We have also demonstrated that near surface anomalies can be imaged, should the operators choose to conduct open-pit excavations. The depth of the interpreted region is currently limited only by the frequency of the antenna. A high-energy, low frequency antenna, (35-70 MHz), may be able to image the pegmatite contacts at depth. Alternative geophysical methods, such as shallow seismic or VLF, could also be employed to determine the subsurface structure.

The interpreted surface scan for Dyke 1 matches very well the underlying mine workings. Both open drifts or declines and geologic features are clearly visible on the recorded scan. (Figure 9). The strength and clarity of the scan of Dyke 1 is very impressive, given the limitations of the recording equipment. Subsequent re-scanning, from the surface, of Dyke 1 with the SIR-II **GPR,** indicated several surface anomalies which have either been excavated or could be excavated easily. The scans of the underground workings are very impressive, given that we have had a 100% positive correlation with our interpretations so far. As mining progresses, and we are able to closely measure the exact distances of the working face to the anomalies, we should be able to improve the accuracy of our interpretation and complete a detailed geologic mapping of the complex features of the Cryo-Genie Pegmatite. The basic statistical approach, plotted on Figure 5, should also aid in planning for continued operations.

In our opinion, **GPR** is proving to be a useful geophysical prospecting tool at the Cryo-Genie Pegmatite Mine. A 3-D survey, using our current technology recording equipment, would provide a complete image of the sub-surface. The preliminary complete underground survey appears to have revealed several pocket anomalies. The **GPR** method was successful in finding pockets at the Himalaya Mine, and it appears that it is also successful at the Cryo-Genie, as suggested in our first trial investigation conducted in January, 2002, (Black, 2002).

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