FINAL REPORT ON THE EVALUATION OF
THE PORTABLE INSTANTANEOUS DISPLAY ANALYSIS SPECTROMETER (PIDAS)

BY R.J.P. LYON, PRINCIPAL INVESTIGATOR
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MAKOTO OHASHI, PASCO CORPORATION, JAPAN
CURRENTLY VISITING SCIENTIST, STANFORD UNIVERSITY

FOR

NASA HEADQUARTERS
WASHINGTON D.C.

NASA GRANT NAGW-1252
(SPO # 4858)
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GRANT TITLE: BASIC RESEARCH & EVALUATION OF THE PIDAS
FIELD SPECTROMETER
PERIOD OCTOBER 1, 1987- NOVEMBER 30, 1988
(FIVE COPIES TO NASA)
JUNE 3, 1988
1. INTRODUCTION AND AIMS OF THE PROGRAM

1.1 General Statement.

The original aims of the project were to evaluate the Portable Instantaneous Display Analysis System (PIDAS) by measuring the spectra of fifty (50) mineral specimens and rock samples under the following conditions:

1. In the laboratory under artificial illumination.
2. Outdoors, on the building "patio", while still using the normal (line voltage) electrical power supplies.
3. Outdoors, in the field (at Yerington, Nevada), using battery power.

In addition, the Stanford Remote Sensing Laboratory (SRSL) owns or had access to three other types of field spectrometers:

1. Geophysical Environmental Research (GER) IRIS Mark IV, a diffraction grating unit;
2. GEOSCAN PFS (West Australia) Circular Variable Filter (CVF) unit, a prototype of a rapid scan, Portable Field Spectrometer (PFS);
3. SPECTRAFAX 440 (from Daedalus Enterprises, Inc.), the US-built production version of the GEOSCAN PFS unit.

The characteristics of these three units are listed in Table I.

Due to PIDAS malfunctions, however, only data from the laboratory and outdoor ("patio") phases of the work were retrievable for analysis.
1.2 Summary of the proposed study effort as per the Grant Statement of Work.

1. PIDAS would be one month at Stanford

2. 125 Spectra would be measured in the following manners:

2.1 Indoors-- 10 standard clays
   25 field samples (Yerington,NV)

2.2 "Patio"-- a. in sunlight-- same 25 samples
    b. under lamp -- same 25 samples

2.3 Field -- a. in sunlight--25 samples from 10 sites.
    (Yerington--Ann Mason, Blue Hills, Buckskin
    Ra.--"Pyrophyllite Ridge" & "Alunite Hill"
    Ludwig skarns).
    b. 25 samples from these locations.

3. In addition PIDAS would be evaluated for (a) same FOV,
   repeated N-times, and (b) at M sub-sites within the
   same 20x20m TM-sized "pixel".

4. The Final Report would:
   (a) compare and contrast PIDAS with the other
   spectrometers available for our use:
   GEOSCAN-PFS;
   DAEDALUS-SPECTRAFAX 440;
   GER IRIS units
   (b) include about 125 spectra,
   and (c) provide those spectra in ASCII files on
   floppy disk(s) in machine readable form.

1.3 Summary of Proposed & Actual Spectra, Taken & Recovered

<table>
<thead>
<tr>
<th>PROPOSED</th>
<th>ACTUAL MEASUREMENTS</th>
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<tr>
<td>TASK PIDAS</td>
<td>PIDAS</td>
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<tr>
<td>TASK PIDAS</td>
<td>Taken Recov'd</td>
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<tr>
<td>1.3.1-Indoors 25 : 143 45</td>
<td>50</td>
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<tr>
<td>1.3.2-Patio-sun 25 : 445 33</td>
<td>50</td>
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<tr>
<td>-lamp 25 : 00 00</td>
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<td>1.3.2-Field-sun 25 : 400 00</td>
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<td>TOTALS 125 : 988 78</td>
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<tr>
<td>FOV (DEG.)</td>
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<td>DISPERSIVE ELEMENT</td>
<td>Gratings</td>
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<td></td>
<td>4 (1-vis</td>
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<td>(856-2490nm)</td>
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<tr>
<td>1400-2500nm</td>
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<td></td>
<td>(700-1400nm)</td>
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<td>(Calculated by G.Swayze, USGS)</td>
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<td>(now 12-bit)</td>
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</table>
2. ACCESS TO PIDAS

PIDAS was made available to Stanford for evaluation on three separate occasions over the six month period from October 1987 through March 1988.

Period A: October 14-16, 1987, used indoors in lab, and only briefly outside.

Period B: November 11-12, 1987, field use only, in Nevada.

Period C: March 22-25, 1988, laboratory and patio use only (by JPL request)

Period C occurred after the PIDAS repairs during winter 1987-1988, which included increasing the data precision from 8 to 12-bit and bypassing of the instantaneous display capability. Only the data from Period C have been reducible to spectra.

Figure 2.1 Field evaluation of the four spectrometers, Yerington, NV. From left to right-- PIDAS, PFS, SFAX440, IRIS, with a New Zealand 8-channel radiometer (hand-held).
3. SUMMARY OF PIDAS TRIAL PERIODS

3.1 PERIOD A: LABORATORY & OUTDOORS, October 14-16, 1987

**PIDAS:** Only one spectrum was ever seen from the "instantaneous" viewing with the PIDAS wand. Considerable trouble was experienced in estimation of the gain-factors in the absence of viewable spectra. Additionally, no software for retrieving and processing data was available. We attempted writing software to reduce the raw PIDAS output to spectral plots, but the attempts were not successful. About 200 spectra were taken during this period, but none were usable.

**PFS (GEOSCAN):** Inoperable due to broken electronics.

**SPECTRAFAX-440 (DAEDALUS):** Unavailable

**GER Mark IV:** Operable, but not used concurrently with the other instruments.

3.2 PERIOD B: FIELD, Yerington, Nevada, November 11-12, 1987

These dates for the field work were determined solely by the availability of PIDAS. Unfortunately these dates also followed a period of light to moderate rain in Nevada. Most clay minerals had absorbed enough moisture so as to be unrecognizable from their shortwave infrared (SWIR) spectra at 2.2 um.

**PIDAS:** Operable for two field days in Yerington and in Virginia City, Geiger Grade, Nevada. About 200 spectra were taken, however, none were viewable, due to either software or memory-storage problems.

**PFS:** Operable, 100 spectra taken, all reduced and plotted.

**SPECTRAFAX440:** Made available to Stanford by Daedalus. Chuck Stanich of Daedalus accompanied us on the fieldtrip to assure the correct use of the instrument. About 220 spectra were taken, all reduced and plotted. Prototype software did not "average" correctly, so the single-spectra plotted below appear quite noisy outside the absorption peak areas.

**GER Mark IV:** Operable, 30 spectra taken. Not all were usable due to high moisture content in the clays, and to atmospheric moisture (relative humidity 50-75 %), leading to very strong absorptions at 1.4 and 1.9 um completely dominating the spectra.
3.3 **PERIOD C: LABORATORY and OUTDOORS, March 22-25, 1988**

The third period followed the re-building of PIDAS after the accident, and the revamping of the electronics from two 8-bit split data streams to one 12-bit single data stream. Because the study was designed to compare the instruments under identical conditions, only a single measurement by PIDAS was used for comparison to the single measurements made by the other instruments. This procedure was used rather than the standard JPL practice of averaging many separate PIDAS spectra to obtain a single result.

**PIDAS:** The system initially worked very well in the laboratory (Day C-1, March 22), but outdoors on the patio (Day C-2, March 23) only the SWIR segments of the data were recoverable. The visible segment apparently was not recorded, or at least recorded incorrectly. The outdoor data set (of Day C-2) was repeated on Day C-4 (March 25); 205 spectra were measured, of which 33 were usable. Subsequently the same samples were measured indoors with the PFS and the GER Mark IV.

**PFS:** Working well, 50 samples measured indoors.

**SFX440:** Not available to Stanford this period.

**GER Mark IV:** Working well. A considerable number of research days were devoted to ensuring that the "mode of operation" selected for the GER Mark IV was one which produced non-noisy spectra, without residual effects (offsets) due to grating changes.
4. COMPARISON OF INDOOR AND OUTDOOR PIDAS DATA

4.1. Geometry of Measurement

Despite our two attempts (October and November 1987) to obtain outdoor/field data we were unable to recover any usable spectra (see Table 1.3). During the third time we had access to PIDAS (March 23-25 1988), after the optical repair and with the new electronic configuration, we measured the sample sets inside the laboratory (with photoflood lamps) and outside using direct sunlight. Because of a poorly operating battery charger the PIDAS was run on line voltage in both locations (lab and patio) using a long extension cord.

In both cases the PIDAS backpack was placed horizontally on a 4-wheel trolley, with the optical head held by a C-clamp viewing downwards. The sample was placed about 30 cm below the head in full illumination from either the lamp or the sun. Phase angles were about 45 degrees. Each sample was measured twice, with a Halon reference measured between each pair of sample measurements.

4.2. Results

Sixteen (16) sample sets (outdoor and indoor) are shown in Set A1-A16, the side-by-side comparison of the spectra allowing one to view their differences. The outdoor set (on the left, coded 0325A.*) were taken on March 25, from about 10 AM to 2 P.M. The indoor set are displayed on the right, coded 0323A.*.

Both sets have had one pass (SM=1) with the "V-filter" smoothing algorithm. This consists of passing a moving window over three adjacent data points N-1 through N+1, and recalculating the value of the central data point N according to the equation $N = \frac{(N-1 * 0.25) + (N * 0.5) + (N+1 * 0.25)}{1}$.

Only single PIDAS spectra are shown. No averaging of multiple spectra (the JPL standard operating procedure) was attempted for any of the spectrometer data (except for one trial with the SPECTRAFAX 440, although the algorithm in their software was found out later not to be working). This procedure was used because the goal was to evaluate the instruments under identical conditions, not necessarily to produce the most noise-free spectra. The reproducibility of individual measurements and the effective instrument precision can not be evaluated by averaging multiple spectra.
Figure 4.1.1 Outdoor ("Patio") measurements, at Stanford. Left: Rob Green and Hiroshi Okayama measuring with optical head mounted on the side of the trolley. The sample was placed on the black plastic topped stool. Right: Close-up of the measurement geometry.
4.2.1 Outdoor Spectra (March 25)

The gain setting for visible wavelengths was clearly set too high, and despite the efforts of the science advisor (Rob Green) we could not get a spectrum viewed on the LCD wand. Spikes are visible in the 1.15 um water-vapor absorption band and were very strong in the 1.4 and 1.9 um regions during preprocessing. We modified our GER plotting program to omit the 1.4 and 1.0 um region date replacing it with horizontal lines (plateau-like regions in the spectral plots).

In the plot program the Y-axis scaling is "floating" to accommodate the maximum and minimum values in the data and to emphasize spectral features. This practice is best for comparing subtle spectral features as detected by the different instruments. Absolute radiometric accuracy was not investigated.

4.2.2 Indoor Spectra (March 23)

Problems in setting gains for the visible region of the spectrum did not appear as markedly as before, but this region showed considerable noise, even after mathematically smoothing the data (SM=1).

4.2.3 Analysis

Despite the negative effects of over-saturation in the visible, and the missing data in the 1.4 and 1.9 um regions, generally the other significant peaks could be seen in the plot. Spectral curve shapes were quite similar for indoor and outdoor measurements, and kaolinite doublets in the 2.2 um region were resolved.
5. COMPARISON OF THE FOUR SPECTROMETERS

5.1. Geometry of Measurement

All spectra were taken indoors under photoflood illumination. Working distances between sample and optics averaged 30 cm. Phase angle of the illumination was 45 degrees to the viewing optics.

No special preparation of the samples was undertaken. For the rock and mineral specimens, the rough natural surfaces were used. For powdered minerals, an untreated "heap" of powder was measured.

5.2. System Availability

5.2.1 PIDAS was available on 3 separate occasions: October 14 to 16 and November 11 to 12, 1987 and March 23 to 25, 1988, for a total of 9 operating days. For a variety of reasons, some electronic, some software, we have been unable to reduce data from the first two dates, and hence only the March 23 - 25 data (after repair) are used.

5.2.2 The GER Mark IV has had only intermittent availability. It is Stanford-owned but has given irregular service. In the 3 years since purchase (with Keck Foundation funding) we have processed over 2500 spectra and some of its recent troubles are due to this length of operation. Recently we had a mechanical failure of the grating rotation (a "freezing-up of the rotor") which was predictable based upon the 2500 spectra throughput.

5.2.3 The PFS is Stanford-owned and available when running. We have had some electronic problems in recent months, but it has usually operated well both in the field and in the laboratory. Several thousand PFS spectra have been collected, but a discussion of their information content is beyond the scope of this PIDAS report.

5.2.4 The SPECTRAFAX 440 was made available for the field evaluation period (November 10 - 12) and for the subsequent week, at no cost, by Daedalus Enterprises, Inc. In addition Daedalus supplied a field engineer (Chuck Stanich) for the first week to train us in the operation of SPECTRAFAX. Only data from those 2
weeks of operation in November are available, and not all of the following pages (B1-B34) have SPECTRAFAX spectra.

Generally a single pass of the V-filter (SM=1) was used to display the data.

5.2.5 Analysis

Thirty-four (34) sets of spectra from the four units have been compiled in Appendix B. They are arranged alphabetically for the standard minerals and by acquisition date for the field samples from Yerington and Virginia City, Nevada.

5.2.5.1 Spectral Coverage (See Table I)

All four spectrometers covered the same general range and are plotted from 500 to 2500 um, except for PIDAS which is shown from 450 to 2450 um. (The vertical grids mark every 100 um.)

5.2.5.2. Spectral Resolution (See Table I)

The uppermost two spectra on each page of the Appendix are for PIDAS and the GER Mark IV, both of which are grating instruments with nominal resolution of 2 - 4 um. As with most optical instruments the modular transfer function (MTF) actually degrades this to a larger value. In the specific case of our GER Mark IV, Glen Swayze of the U.S. Geological Survey in Denver has determined the true spectral resolution to be 35 um at 2300 um using both pyrophyllite and datolite standard samples (originally measured on the USGS 1 um resolution spectrometer in Denver).

The lowermost two spectra on each page are for PFS and SPECTRAFAX respectively, each using a circular variable filter (CVF) as their dispersive element. As a result of the CVF design, spectral resolution is not fixed, but varies linearly with wavelength, increasing at a fixed percentage (1 - 3%) of each wavelength. To cover the 450 - 2500 um spread, three (3) wheel segments are needed, each with its own percentage bandpass.

The SPECTRAFAX has a better CVF wheel than the older PFS, and has 1% resolution from 1200 to 2400 um. This gives a 12 um bandpass at 1200 um but degrades to 24um at 2400um. (22 um at 2200 um is the region of shortwave infrared absorption caused by metal-hydroxyl bonds, one of our main interests). This 14um resolution can just resolve the Kaolinite (and Dickite) doublets at 1410 (B21, B8), but not the Kaolinite doublet at 2200 (except B21).
A mathematical algorithm can be used to "increase" the resolution by deconvolving the modular transfer function from the raw spectrum, but its use is not warranted on all spectra (H. Zhu, Masters Thesis, Stanford University, 1987).

5.2.5.3 PIDAS

Indoor spectra from the March 23 measurements were used for this presentation, with a single pass of the V-filter used for display (SM=1). The visible section is still very noisy, but the broad shape is correct, and is modified in samples with ferric iron (B6, B11, B12, B18, etc.).

Variations in the PIDAS spectra with different amounts of smoothing (SM=0,1,3,5) are shown in Figure 5.2.5.3.A. Because of the large number of data points in PIDAS spectra, these smoothing values show little effect. With high data-density curves such as those from PIDAS, a moving window of width three (i.e. three points used for each pass of the smoothing filter) has a much less visible effect than on curves consisting of fewer data points.

Some grating-change effects (B3, B6, B7, B16, etc.) appear randomly in the spectra at 850 um, for no apparent reason.

5.2.5.4 GER Mark IV

Indoor spectra, mostly from a set of measurements run on May 13, 1988, are used in these figures. Smoothing by 3 passes (SM=3) was used as this is our normal operating procedure.

The spectra are clean, well resolved and very repeatable. Absorption features occur at the same location (wavelength) and have the same depth (percent reflectance) in separate measurements of the same sample. Both of these spectral characteristics are important in spectral recognition, and are used in the SRSL pattern recognition program "STANXPRT".

We feel strongly that the GER Mark IV is as good as, if not better than, PIDAS, in both radiometric resolution and precision, for approximately 5% of the cost (and probably 10% of Daedalus' rough estimate of the cost of PIDAS-II - see below.) The GER Mark IV is certainly lighter in weight, smaller in volume, and electronically more reliable than PIDAS.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Price</th>
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<tbody>
<tr>
<td>GER Mark IV</td>
<td>$58,000 Double beam</td>
</tr>
<tr>
<td>PIDAS-I</td>
<td>$1,300,000 Single beam</td>
</tr>
<tr>
<td>PIDAS-II</td>
<td>$650,000 Single beam</td>
</tr>
<tr>
<td>MINI-IRIS</td>
<td>$28,000 Single beam (under fabrication)</td>
</tr>
</tbody>
</table>
Indoor spectra are mostly from measurements done on March 30. After three years of use the visible segment of the CVF is now badly "crazed" and the metal-oxide coating is disintegrating, seriously contributing to the noise in that part of each spectrum. The remaining segments, which are of most interest (1200 - 2500 um), are intact and produce good spectra.

While a CVF instrument has lower resolution than a grating instrument, especially at longer wavelengths, the positions of the absorption minima in CVF spectra (although broadened) are still sufficiently constrained so as to be diagnostic. The SRSL automated pattern recognition program works well with these PFS spectra as input. The database for automated recognition of CVF spectra is different than that for grating spectra to account for the difference in resolution.

The lower resolution of CVF spectra at longer wavelengths can be clearly seen in the dickite sample (B8) where the 1400 um doublet is resolved, but not the 2200 um doublet.

Fig. 5.2.5.5.1
Field use of the PFS. Backpack holds batteries only.

5.2.5.6 SPECTRAFAX

Only 17 SPECTRAFAX spectra of mineral specimens and field samples are shown in Appendix B. Many more were successfully taken from November 10 - 20 but are not included in this PIDAS evaluation.

SPECTRAFAX spectra closely resemble the PFS datasets, but have better spectral resolution (B21, C6).
6. EVALUATION OF THE FOUR SPECTROMETERS

6.1 PIDAS

(1) The instrument is a top-heavy backpack, and almost dangerous to use on steep rocky slopes. Needs redesign of backpack for better carrying stability.

(2) An "averaging N-spectra" mode (automatic) would avoid the considerable number of "wand" actions required, for what has become the "Standard Operational Mode", i.e. taking 5 spectra consecutively, for later averaging. One may wish to retain the actual N single-spectra, for later investigation of variance, rather than the PFS method of storing only the "average-of-N-spectra.

(3) Some considerable thought should be devoted to the ergometrics of instrument operation. This does not mean that the System Software ("firmware") has to be available to every user, but that some options must be programmed into the system, so as to make it more adaptable for easy use. At present PIDAS is anything but "user friendly".

(4) The firmware in PIDAS could be greatly improved by including a sample description in each data file. The description could be entered via the keyboard on the wand. In its present configuration, the PIDAS user must carry a notebook to correlate sample descriptions to the arbitrary sample name given by PIDAS. This procedure can create considerable confusion in field conditions as well as during data reduction in the laboratory, which may occur days after the measurements are taken.

(5) An additional improvement in firmware would be to allow an arbitrary number of spectra to be measured and/or transferred to a separate computer. In the present configuration, data must be handled in large blocks (144 spectra). In retrieving data for later analysis, both the block name and the number of the spectrum within the block must be correlated with the handwritten descriptions in a field notebook. PIDAS software can make separate files from these data, but doing so is an extra, unnecessary step in processing, and additional software is then required to perform operations on the resulting files.

(6) A self contained artificial light source would be extremely useful, and would contribute only marginally to the already considerable weight and complexity of the existing instrument.

(7) Spectral resolution is good when the instrument is operating properly, but there is considerable variability between identical measurements of a sample.
(8) The extremely high nominal spectral resolution in wavelengths measured by the silicon detectors is impressive, but the noise in many of the spectra suggest that a better approach might be to measure broader wavelength intervals in order to increase the signal-to-noise ratio.

(9) The standard operating procedure calls for measuring each sample multiple times (usually two to five), and measuring a reference such as Halon between each sample set. Thus for a single spectral plot of a single sample, from two to six data files are created. This is far more redundancy than with any other instrument, and should not be necessary.

6.2 GER Mark IV

(1) The GER Mark IV is not (yet) really "backpackable", although we are experimenting with this concept. A packframe base will make the unit much more maneuverable, although the optical head (6.4 kg) is itself rather heavy.

(2) The GER Mark IV will always suffer from an inability to simply view the measured spectrum, prohibiting any real-time decision making. Even the inclusion of a "lap-top" PC in the framepack will only allow "post facto" viewing or decision making ("expert system" implementation).

(3) Although somewhat temperamental, the GER instrument produces the most useful spectral data, when it is working.

6.3 PFS

(1) The optical head is too heavy (4.5 kg) and not well balanced with its center of gravity too far forward. After 20-30 minutes of use, holding the unit is quite tiring.

(2) The PFS is unique in allowing truly instantaneous viewing of spectral plots while being used in portable field mode. We feel that the inclusion of a spectrum-viewing LCD is a VITAL part of the field attributes of these spectrometers, the absence of such LCD's allowing either too many spectra to be stored, or the "mapping process" to continue without real-time knowledge of the material being mapped. In addition, when an instantaneous view of the spectrum is available, real-time decisions can be made about the mineralogy itself, whether the gain should be adjusted to enhance spectral contrast, or simply which spectra are to be stored.

(3) Spectral resolution is noticeably lower than that for the grating instruments, but is adequate for resolving many of the features necessary for discriminating different mineral species.
6.4 SPECTRAFAX

(1) The SPECTRAFAX 440 unit is very well designed from a "portability" point of view. The backpack mounting sits easily on the back, and the hand-held optical head is comfortably to use, without excessive weight. All operators who have used this unit were very happy with the design - often volunteering to wear the SPECTRAFAX longer, rather than to "wear" the PIDAS, or even use the lighter-weight GEOSCAN PFS. Ergometrically the design is excellent.

(2) Spectral resolution is comparable to that of the PFS.
7. ANALYSIS & RECOMMENDATIONS

We do not recommend PIDAS as the best field spectrometer available. It is far too expensive for what it offers. A point can perhaps be made that its radiometric accuracy is the best of available instruments, but we did not evaluate this aspect of its performance. Our results indicate that relative spectroscopy is not its asset either,

It is very clear that while Circular Variable Filter (CVF) units offer mobility, speed and ease of use over the grating units, their loss of spectral resolution at longer wavelengths (in each wheel segment) leaves them at a disadvantage. However, for many of the applications for field spectrometers, and especially for vegetation analysis (chlorophyll, leaf structure etc.), the CVF approach is imminently suitable.

Much of our research is devoted to mineralogical determinations under field conditions. After a reasonably complete evaluation of PIDAS under varying operational conditions, we do not see the need for such a unit for making geologically significant measurements in the field, especially since the GER grating unit has out-performed the (present-status) PIDAS in all aspects of this study. The fact that the GER Mark IV unit costs only five (5) percent of the assumed PIDAS cost (1.3 million dollars) is further reason not to use it. From a management point of view we cannot see investing any more funds in PIDAS, when the same amount of funds could buy many grating units essentially off-the-shelf. The newer GER "Mini IRIS", a single-beam version of the Mark IV now under construction, will lower the price of a grating instrument to three (3) percent of PIDAS present costs.

What we field experimenters need is MORE grating-type units - not a proliferation of more elegant or exotic units which we can seldom get to use.
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APPENDIX

PLOTS OF MEASURED SPECTRA
Set A: PIDAS Outdoor (patio) and indoor for a set of 16 samples.

1. Alunite A% Sulfur, NV
2. Alunite A20 Sulfur NV
3. Dickite 29352 Cusihuriachi
4. Dickite API-H14 Ouray, CO
5. Epidote 5538 Camp Apache
6. Epidote 66077 Garnet Hill
7. Jadeite 5558 Clear Creek, San Benito, CA
8. Jadeite 62771 Clear Creek, San Benito, CA
9. Kaolinite 25365 Riverside, CA
10. Kaolinite KGA-1 CMS Standard Clay (well crystallized)
11. Kaolinite KGA-2 CMS Standard Clay (poorly crystallized)
12. Pyrophyllite 62596 Mariposa, CA
13. Pyrophyllite PYS1A USGS Standard
14. Pyrophyllite P-S RJPL (sand) standard
15. Talc 51485
16. Talc Nottage (with carbonate?)
Set B: Comparison of Four Spectrometers, Indoors.

Arranged with PIDAS in the upper left, GER Mark IV (IRIS) in the upper right, PFS in the lower left, and SPECTRAFAX in the lower right.

1. Alunite A-5 Sulfur, NV, block
2. Alunite A-20 Sulfur, NV, powder (PFS average of 3 spectra)
3. Buddingtonite FA04-11A Buddingtonite Bump, Cuprite, NV
4. Calcite C-99, sand, RJPL 0.5mm
5. Calcite 29349 Riverside, CA (blue)
6. Datolite 51397 New Jersey (brown)
7. Datolite 51399 Massachusetts (white) USGS standard
8. Dickite API-H14 Ouray, CO
9. Dickite 29352 Cusihuriachi, Mexico
10. Dolomite 66313 Carson Hill, CA
11. Epidote 5538 Camp Apache, AZ
12. Epidote 66077 Garnet Hill, Calaveras Co., CA
13. Gypsum G-90 RJPL (sand sized)
14. Illite IMT-1 (1MD) CMS, Silver Hill, MT
15. Illite ISMT-1 CMS Illite-Smectite mixed layer
16. Jadeite 5558 slab, Clear Creek, San Benito, CA
17. Jadeite 62771 vein, Clear Creek, San Benito, CA
18. Jarosite Argentina (GAP)
19. Kaolinite KGA-1 CMS well crystallized
20. Kaolinite KGA-2 CMS poorly crystallized
21. Kaolinite 25365 Riverside, CA
22. Kaolinite CSIRO (3.8.84)
23. Kaolinite K-N Nottage
24. Kaolinite Ball clay
25. Montmorillonite STX-1 Na-Mont, CMS
26. Montmorillonite SAZ-1 Ca-Mont, CMS
27. Montmorillonite SCA-2 moist, CMS
28. Nontronite NG-1 CMS Hagen Hagen, Germany
29. Pyrophyllite PYS1A USGS standard
30. Pyrophyllite PS-101 RJPL (sand)
31. Pyrophyllite 62696 Mariposa, CA
32. Pyrophyllite 64266 Blendon, NC
33. Serpentine 30032 San Benito, CA
34. Talc 51485 flat slab New York
35. Talc Nottage fine powder, impure
Set C: Rock samples from Yerington, Nevada, as collected in the field. Rock unit names (e.g. Jpqm for #1) are from Proffett and Dilles, 1984, Geologic Map of the Yerington District, Nevada Bureau of Mines Publication #77.

Samples from Yerington, Singatse Range:

1. GB11-11 Jpqm, sericitic, bleached iron stain
2. GB11-21 Jpqm chloritic (greenish), YAM/YMP
3. GB11-31 Jgd with fresh biotite, YAM/YMP
4. GB11-64B soil under desert pavement, light grey, bubbly, YAM

Samples from Yerington, Buckskin Range:

5. GB11-64BL true soil underneath sample GB11-64B
6. GB11-71 DDH site, alunite/pyrophyllite, Alunite Hill, YBK
7. GB11-72E DDH site, altered tuff (chlorite?), YBK
8. GB11-74 Pyrophyllitic tuff, YBK
9. GB11-74B same as GB11-74 but tourmaline rich, sericitic, YBK
10. GB11-75 white pyrophyllite, YBK

Samples from Virginia City:

11. GB12-11 Altered Kate Peak Tuff, VCE
12. GB12-43 altered tuff, VCN
13. GB12-52 altered tuff (alunite), VGN