Progress Energy

Serial: NPD-NRC-2009-142 10 CFR 52.79
July 1, 2009

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555-0001

**LEVY COUNTY NUCLEAR POWER PLANT, UNITS 1 AND 2
DOCKET NOS. 52-029 AND 52-030
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION LETTER NO. 035 RELATED TO SURFACE FAULTING**

Reference: Letter from Brian C. Anderson (NRC) to Garry Miller (PEF), dated May 8, 2009, "Request for Additional Information Letter No. 035 Related to SRP Section 2.5.3 for the Levy County Nuclear Plant Units 1 and 2 Combined License Application"

Ladies and Gentlemen:

Progress Energy Florida, Inc. (PEF) hereby submits our response to the Nuclear Regulatory Commission's (NRC) request for additional information provided in the referenced letter.

A partial response to the NRC request is addressed in the enclosure. The enclosure also identifies changes that will be made in a future revision of the Levy County Nuclear Power Plant Units 1 and 2 application.

If you have any further questions, or need additional information, please contact Bob Kitchen at (919) 546-6992, or me at (919) 546-6107.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on July 1, 2009.

Sincerely,

G. D. Miller

Garry D. Miller
General Manager
Nuclear Plant Development

Enclosure

cc: U.S. NRC Region II, Regional Administrator
Mr. Brian Anderson, U.S. NRC Project Manager

D094
NRO

bcc: John Elnitsky, VP-Nuclear Plant Development
Robert Kitchen, Manager-Nuclear Plant Licensing
Tillie Wilkins, NPD-Licensing
John O'Neill, Jr. (Pillsbury Winthrop Shaw Pittman, LLP)
A. K. Singh (Sargent & Lundy, LLC)
Cynthia Malecki (Sargent & Lundy, LLC)
Lorin Young (CH2M HILL)
John Archer (WorleyParsons)
NPD Document Control Inbox (Records: Correspondence)
File: NGG-NPD (Dawn Bisson)

Levy Nuclear Power Plant Units 1 and 2
Response to NRC Request for Additional Information Letter No. 035 Related to SRP Section 2.5.3 for the Combined License Application, dated May 8, 2009

NRC RAI #	Progress Energy RAI #	Progress Energy Response
02.05.03-1	L-0331	NPD-NRC-2009-106, dated June 23, 2009
02.05.03-2	L-0332	Future Response
02.05.03-3	L-0333	Response enclosed – see following pages
02.05.03-4	L-0334	Future Response
02.05.03-5	L-0335	Future Response
02.05.03-6	L-0336	Future Response
02.05.03-7	L-0337	Future Response
02.05.03-8	L-0338	NPD-NRC-2009-106, dated June 23, 2009
02.05.03-9	L-0339	NPD-NRC-2009-106, dated June 23, 2009
02.05.03-10	L-0340	Response enclosed – see following pages

Attachment	Associated RAI #	Pages Included
Reference RAI 02.05.03-01	L-0333	13

NRC Letter No.: LNP-RAI-LTR-035

NRC Letter Date: May 8, 2009

NRC Review of Final Safety Analysis Report

NRC RAI NUMBER: 02.05.03-3

Text of NRC RAI:

FSAR Section 2.5.3.2.1.1 (pg 2.5-180) states that erosion and channel development are enhanced in "zones of weakness caused by upward propagation of lineaments through unconsolidated sediments." However, the mechanism for this upward propagation of lineaments, which commonly reflect fracture systems or faults, is not discussed to indicate whether it is non-tectonic in nature.

In order for the staff to assess the importance of a mechanism that would cause a lineament to propagate upward through unconsolidated sediments, please explain why this upward propagation occurs in regard to whether the mechanism is non-tectonic in character.

PGN RAI ID #: L-0333

PGN Response to NRC RAI:

Culbreth (Reference 2.5.3-212) made the following observations and conclusions based on geophysical investigation of photolineaments in South Florida:

- Some lineaments are associated with a gravity anomaly (density gradient) that can be modeled as a geologic feature in the sub-Zuni basement, indicating that some lineaments may be surface manifestations of basement features.
- Other nearby lineaments do not show a gravity signature, indicating that not all lineaments represent basement structures that can be detected by density gradients.
- Structures that are not characterized by density contrasts, such as fractures within crustal blocks and "strike-slip" faults between blocks of the same density may underlie some lineaments.
- Gravity anomalies were observed in some profiles that do not correspond to any mapped lineaments.
- Lineaments may also reflect changes in stratigraphy or be the result of other surface or near-surface processes.
- Surface characteristics, such as geomorphology and cultural intensity, may influence the recognition of lineaments at the surface.

Culbreth suggests that a possible explanation of the manifestation of basement structures overlain by 2 to 5 km of sedimentary rock as lineaments at the present ground is that lineaments are propagated upward through overlying material through stresses induced by Earth tides. This hypothesis assumes that a localized, increased response to Earth-tide forces at discontinuities or zones of decreased rigidity, such as along faults or other vertical discontinuities in the basement, creates stresses in the overlying rock that leads to fracturing. Zones of fractures are created, then enhanced by diagenetic processes, resulting in increased weathering and possible faulting. This process results in the manifestation of a subsurface feature through overlying sediments.

Fractures are caused by many different processes, including stress release as a result of tectonic movement, tidal stresses, and other processes. Upchurch (Reference RAI 02.05.03-01) also suggests that tidal stresses and, perhaps, residual movement during the middle and late Tertiary have resulted in translation of fractures and possible minor faults into younger strata in Florida. Upchurch notes that for the most part the movements appear to have resulted in warping of strata rather than faulting. Additionally, Upchurch outlines a number of nontectonic mechanisms that would lead to the expression or translation of a fracture through unconsolidated sediments overlying competent rock, including the following

- Settlement of unconsolidated sediments into solution-enlarged fractures in the underlying, consolidated strata.
- Differential weathering, illuviation, or erosion caused by groundwater movement across karst surfaces.
- Differential consolidation of sediments into relict erosional features preserved in underlying unconformity surfaces.

Growth of vegetation in clay- or silt-rich, moisture-holding soils located over somewhat deeper bedrock features associated with fractures.

References:

Reference RAI 02.05.03-01, Fractures and Photolineaments: Introduction and Analysis Methodology, by Sam B. Upchurch, Ph.D., P.G. (SDI Global)

Associated LNP COL Application Revisions:

Revise the following portion of FSAR Section 2.5.3.2.1.1, from:

"Culbreth (Reference 2.5.3 212) completed a series of gravity profiles across selected lineaments in south Florida to determine if lineaments represent surface manifestations of basement structures. From that study, Culbreth (Reference 2.5.3 212) identified four factors that may affect lineament distribution and density. The four factors include the (1) type, scale, and resolution of the imagery; (2) techniques used for mapping; (3) prevalence of cultural features; and (4) geomorphology of the study area. The impact of the first two features on lineament identification is predictable, whereas the impact of cultural features and geomorphology can complicate the interpretation of the lineament analysis. In areas where there is a low lineament density, there is commonly high urban development. The urban development alters the landscape and obscures features used to identify lineaments. (Reference 2.5.3 212)

The effect of geomorphology on lineament density is also directly related to the amount of topographic relief for the area. (Reference 2.5.3 212) In areas characterized by multiple marine terraces and well developed drainage patterns, headward erosion across the marine terraces and channel development is enhanced in zones of weakness caused by upward propagation of lineaments through unconsolidated sediments. Evidence of lineament control on erosion and channel development is supported by the nearly rectilinear drainage patterns observed in many streams through the area. (Reference 2.5.3 212) In areas characterized by parallel, shallow, swampy depressions between beach ridges, the linear features observed on satellite images and air photos are a result of the beach ridges rather than fracture traces or lineaments propagating upward through the sediments. The beach ridges have imparted a fabric to the area that hinders the identification of lineaments."

To read:

"Culbreth (Reference 2.5.3 212) completed a series of gravity profiles across selected lineaments in south Florida to determine if lineaments represent surface manifestations of basement structures. The profiles led Culbreth to make the following observations and conclusions:

Some lineaments are associated with a gravity anomaly (density gradient) that can be modeled as a geologic feature in the sub-Zuni basement, indicating that some lineaments may be surface manifestations of basement features.

Other nearby lineaments do not show a gravity signature, indicating that not all lineaments represent basement structures that can be detected by density gradients.

Structures that are not characterized by density contrasts, such as fractures within crustal blocks and "strike-slip" faults between blocks of the same density, may underlie some lineaments.

Gravity anomalies were observed in some profiles that do not correspond to any mapped lineaments.

Lineaments may also reflect changes in stratigraphy or be the result of other surface or near-surface processes.

Surface characteristics, such as geomorphology and cultural intensity, may influence the recognition of lineaments at the surface.

Culbreth suggests that a possible explanation of the manifestation of basement structures overlain by 2 to 5 km of sedimentary rock as lineaments at the present ground is that lineaments are propagated upward through overlying material through stresses induced by Earth tides. This hypothesis assumes that a localized, increased response to Earth-tide forces at discontinuities or zones of decreased rigidity, such as along faults or other vertical discontinuities in the basement, creates stresses in the overlying rock that leads to fracturing. Zones of fractures are created, and then enhanced by diagenetic processes, resulting in increased weathering and possible faulting. This process results in the manifestation of a subsurface feature through overlying sediments.

Culbreth (Reference 2.5.3 212) identified four factors that may affect lineament distribution and density. The four factors include the (1) type, scale, and resolution of the imagery; (2) techniques used for mapping; (3) prevalence of cultural features; and (4) geomorphology of the study area. The impact of the first two features on lineament identification is predictable, whereas the impact of cultural features and geomorphology can complicate the interpretation of the lineament analysis. In areas where there is a low lineament density, there is commonly high urban development. The urban development alters the landscape and obscures features used to identify lineaments. (Reference 2.5.3 212)

The effect of geomorphology on lineament density is also directly related to the amount of topographic relief for the area. (Reference 2.5.3-212) In areas characterized by multiple marine terraces and well developed drainage patterns, headward erosion across the marine terraces and channel development is enhanced in zones of weakness. Evidence of lineament control on erosion and channel development is supported by the nearly rectilinear drainage patterns observed in many streams through the area. (Reference 2.5.3-212) In areas characterized by parallel, shallow, swampy depressions between beach ridges, linear features observed on satellite images and air photos are a result of the beach ridges rather than manifestations of fractures in bedrock that have propagated upward through the sediments. The beach ridges have imparted a fabric to the area that hinders the identification of lineaments.

Upchurch (Reference RAI 02.05.03-01) states that fractures are caused by many different processes, including stress release as a result of tectonic movement, tidal stresses, and other processes. A fracture refers to one of three distinct structures that include faults, shear fractures, and joints. Faults are defined as penetrative fracture planes along which displacement has occurred. Shear fractures and joints are fracture planes that have experienced imperceptible movement. Shear fractures are formed in the same way as faults with a shear parallel to the fracture, but with negligible amounts of displacement. Joints are opening mode fractures that commonly form in systematic orientations and vary in spacing and length depending on rock thickness and stiffness. Joints form to permit minor adjustments in the host rock bodies in which they form. Joints form as the host rock changes in location, orientation, size, and/or shape in response to such actions as burial and ompaction, heating and expansion; uplift, cooling, and contraction; and tectonic loading. A more complete discussion of fracture systems will be provided in RAI 02.05.01-39.

The expression of a fracture in unconsolidated sediments overlying competent rock may result from a number of nontectonic factors as outlined by Upchurch (Reference RAI 02.05.03-01):

- Settlement of unconsolidated sediments into solution-enlarged fractures in the underlying, consolidated strata.
- Differential weathering, illuviation, or erosion caused by groundwater movement across karst surfaces.
- Differential consolidation of sediments into relict erosional features preserved in underlying unconformity surfaces.
- Growth of vegetation in clay- or silt-rich, moisture-holding soils located over somewhat deeper bedrock features associated with fractures."

Reference RAI 02.05.03-01, will be added to the FSAR

Attachments/Enclosures:

Reference RAI 02.05.03-01

NRC Letter No.: LNP-RAI-LTR-035

NRC Letter Date: May 8, 2009

NRC Review of Final Safety Analysis Report

NRC RAI NUMBER: 02.05.03-10

Text of NRC RAI:

FSAR Figures 2.5.3-206, 2.5.3-209, 2.5.3-212, 2.5.3-206, 2.5.3-218, and 2.5.3-220 show lineaments within the site area or site location. There is no designation in the legends of these figures to indicate whether they are interpreted as fractures or faults, although the FSAR text generally states they are not interpreted as faults. It is known that such planar structures can exercise strong control on dissolution.

In order for the staff to understand information related to possible density of regional fracture patterns within the site area and at the site location which may exercise strong controls on dissolution, please indicate in the figure legends whether the lineaments are generally interpreted as fractures or faults or some other type of geomorphic feature.

PGN RAI ID #: L-0340

PGN Response to NRC RAI:

Figures 2.5.3-206, 2.5.3-209, and 2.5.3-212 all show lineaments identified by the Remote Sensing Section of the State Topographic Office Florida Department of Transportation (FDOT) based on interpretation of 16 multispectral images taken by NASA/or Earth Resources Technology Satellite from an altitude of 570 miles. The lineament analysis was done at a statewide scale and identified more regionally continuous lineaments. The FDOT mapping identifies the features only as "lineaments" and does not infer an origin or structural association for the features mapped. Based on a review of additional data (LANDSAT and hillshade models from DEM data), FSAR Section 2.5.3.2.1.2 states that

> "A broad, northwest-trending topographic low area marked by greater stream incision is present in the eastern part of the study area north of the Withlacoochee River; linear features within this broad zone coincide in part with fracture trends/lineaments identified by both Vernon [Reference 2.5.3-203] and the Florida DOT [Reference 2.5.3-211] [Figure 2.5.3-211 and Figure 2.5.3-212]. The general elevation of the geomorphic surface on either side of the depression is similar, and there are no systematic steps across individual linear features within this zone to suggest surface fault displacement. It is likely that this zone represents a zone of greater dissolution localized along fracture trends that has been enhanced by fluvial incision and channel erosion during paleo sea level high stands."

Figures 2.5.3-218 and 2.5.3-220 show lineaments identified from interpretation of a hillshade relief map derived from detailed LIDAR data and 1949 aerial photography. These figures designate the type of lineament (i.e., topographic break or alignment of circular depression [wetlands]). The concluding paragraph of FSAR Section 2.5.3.2.1.3 states that

> "The linear features mapped in the site location are interpreted to be due to differential carbonate dissolution localized along joints and enhanced by marine erosion during previous sea level high stands."

Lineament analysis is one of multiple approaches used to (1) evaluate structural trends (i.e., spatial patterns and density of fractures, joints, or faults) and (2) identify topographic or linear features in a landscape that may be indicative of geologically recent faulting. Additional discussion of the structural implications of lineaments in the site area and site location is provided in the Responses to RAI 02.05.01-10 and RAI 02.05.03-06. This RAI requests that additional interpretative information regarding the origin or cause of the lineament be added to the figures. The figures are strictly meant to show the interpretations of linear features expressed as anomalous topographic and vegetation patterns in the site area and site location as inferred from analysis of remote sensing. As noted by Upchurch (Reference RAI 02.05.03-01) features observed in satellite or remote sensing imagery should be termed a photolineament until it can be confirmed as a fracture.

The FSAR in Section 2.5.3.2.1.3 (pp. 2.5-182) states that lineaments at both the regional (major fracture sets) and local scale are judged to be due to differential dissolution or erosion localized along fractures or joints. This conclusion, which considers other information regarding fracture trends described at the Crystal River plant, fractures mapped in Avon Park Formation elsewhere in the site vicinity, and lack of apparent offset of marine terrace surfaces that would be indicative of Quaternary faulting, is better discussed in the text and should not be added to the legends of the figures.

References:

RAI 02.05.03-01, Fractures and Photolineaments: Introduction and Analysis Methodology, by Sam B. Upchurch, Ph.D., P.G. (SDI Global)

Associated LNP COL Application Revisions:

None

Attachments/Enclosures:

None

Attachments To Letter NPD-NRC-2009-142

Fractures and Photolineaments: Introduction and Analysis Methodology

Sam B. Upchurch, Ph.D., P.G.
Senior Principal Geologist
SDII Global Corporation
Tampa, Florida

Introduction

There is considerable confusion about the terms fracture trace and photolineament. A **fracture trace** is a confirmed fracture in the underlying rock that has sufficient extent as to be visible through remote sensing or other forms of mapping. A **photolineament** is an unconfirmed alignment of features that may, or may not, reflect an underlying fracture. Photolineaments can be caused by spurious alignments of naturally occurring features, livestock trails, human activities, and image processing. Until an underlying fracture has been confirmed, one should always use the term photolineament in lieu of fracture trace.

Figure 1 – Dissolution-enlarged joints (fractures) in the Eocene Ocala Limestone near Lecanto, Florida.

Fractures - Fractures are cracks that occur in many different sediments and rock types. Fractures have been studied for many years because of their relationships to earth movements, groundwater flow, and economic mineral deposits.

Fractures typically have the following properties:

- They normally form linear patterns when viewed from above in aerial photographs and satellite images,
- They represent planes that are nearly vertical in orientation (Figure 1), and
- They occur in statistically similar compass orientations.

A **fracture** is a surface along which the material has lost cohesion. Fractures may, or may not, be related to movement of the rock or sediment. Fractures along which movement has occurred are **faults**. **Fissures** are fractures where the walls of the fracture have moved apart. **Joints** are fractures along which movement has been negligible. When the joints are in limestone or other soluble rock, joints may be enlarged by dissolution of the rock by percolating groundwater (Figure 1).

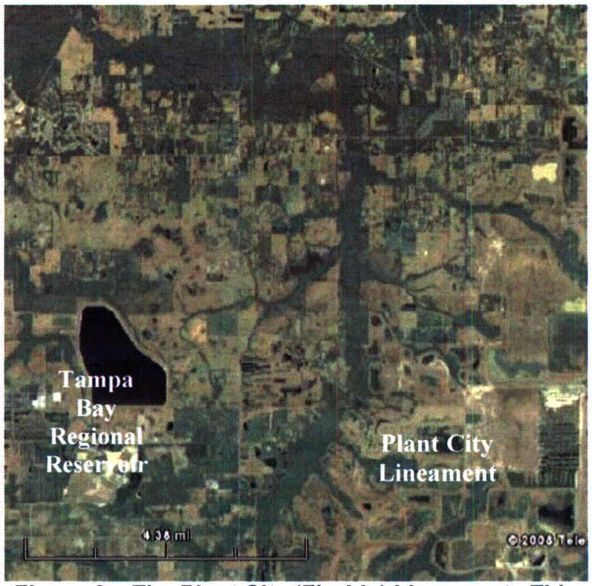

Figure 2 – The Plant City (Florida) Lineament. This north-south photolineament was confirmed as a fracture trace related to faulting in pre-Tertiary basement rocks using microgravity techniques (Culbreth, 1988).

A group of parallel fractures is termed a **set**. Two or more sets that intersect at more-or-less consistent angles are termed a fracture **system**. Fractures that form sets or systems with a geometric pattern are **systematic fractures**. Fracture systems where the two or more orientations appear to have formed simultaneously are termed a **conjugate system**.

Fractures can extend to great depths. For example, Lattman and Matzke (1964) were able to determine that fractures extended to depths of over 3,000 feet at a site in Arizona, and Culbreth (1988) was able to show using microgravity techniques that several large-scale fractures extend to depths of several thousand feet in Florida.

Fractures occur at many different scales from cracks that are only visible in thin section or hand sample to large-scale features (photolineaments; see below) that can be seen in satellite images (Figure 2). Figure 3 illustrates fractures that can only be seen at the outcrop level. These fractures are true joints in that there has been no movement along the surfaces of the fractures. The fractures are a result of cooling and shrinkage of basaltic lava, and the fractures form polygonal features known as columnar joints.


Figure 3 – Columnar joints in basalt near Spokane, Washington. These joints were caused by material shrinkage as the lava cooled.

Classification of fracture-related features that can be observed through remote sensing (aerial photographs and satellite images) is based on the size of the feature (Lattman, 1958), as follows:

Fracture trace:	Length < 1 mile
Lineament:	Length > 1 mile

Figure 2 illustrates a satellite image of a portion of eastern Hillsborough County, Florida, and a linear stream segment that is incised in a photolineament that is over 25 miles in length. This lineament, the Plant City Lineament, can be recognized by alignments of stream segments, sinkholes, and other karst-related landforms. The trace seen in the satellite image is properly termed a photolineament until it can be confirmed as a fracture. In the example shown in Figure 2, the feature was confirmed as a fracture by microgravity (Culbreth, 1988).

Photolineaments – Photolineaments are more-or-less linear features observed on otographs, satellite images, or other remote sensing methods. These linear features may represent fractures in the underlying rock, cultural features (pipelines, cattle paths, etc.), artifacts of the imagery (raster lines, etc.), or other origins. Photolineaments should be verified prior to concluding that they represent fracture traces.

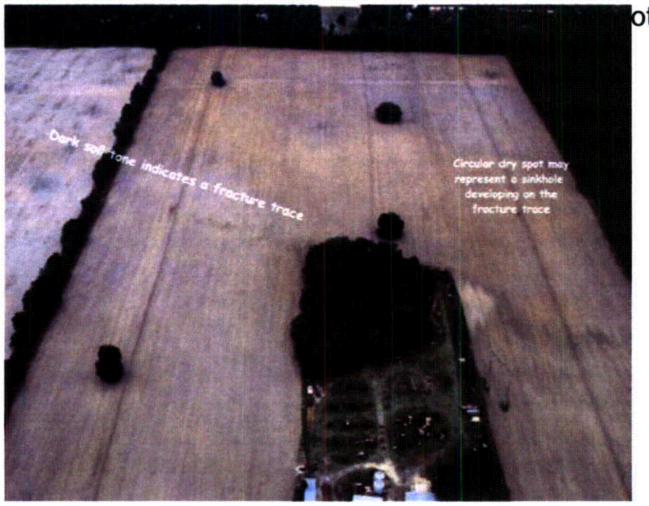

Figure 4 – Example of a photolineament identified by the dark soil tones and confirmed as a fracture trace. The light colored area to the left of the house site is a developing sinkhole within which soil moisture has been reduced. Photograph from a site in Gilchrist County, Florida.

The features one typically utilizes to delineate photolineaments in an aerial photograph or satellite image include:

(1) Alignments and elongations of three or more depressions (potential sinkholes; sinkhole lakes);

(2) Alignments of soil tones (Figure 4);

(3) Alignments of vegetation patterns; and

(4) Alignments of stream segments and stream valleys.

While they are not true photolineaments, alignments of closed depressions as depicted on topographic maps are considered to be ["photo"] lineaments, as well.

Importance of Fractures and Photolineaments

Identification of fractures in rock is important because of the information their orientations may provide as to the tectonic history of an area and the economic importance of the fractures to mineral deposits, groundwater flow, and sinkhole development.

In Florida, we are mainly concerned with groundwater flow and sinkhole development. Identification of fractures on a regional scale is important because the flow of groundwater tends to preferentially occupy the fractures owing to higher permeabilities within the fractures as compared to the bulk host rock. Lattman and Parizek (1964) showed that exploration for groundwater could be greatly enhanced by identification of fractures, especially intersections of fractures. Identification of fracture trace intersections has since become a standard investigation procedure for locating water-supply wells. Similarly, Littlefield et al. (1984) showed that sinkhole occurrences tend to favor fracture traces and fracture trace intersections.

Today, there is a large body of work demonstrating the utility of identification of fractures for sinkhole risk evaluations and for groundwater exploration. Most of the identification work is performed utilizing aerial photographs and satellite images (Figure 2).

Ground truthing of the fracture trace identifications should be utilized to confirm that the features identified on these images represent fractures, but that is seldom done. More

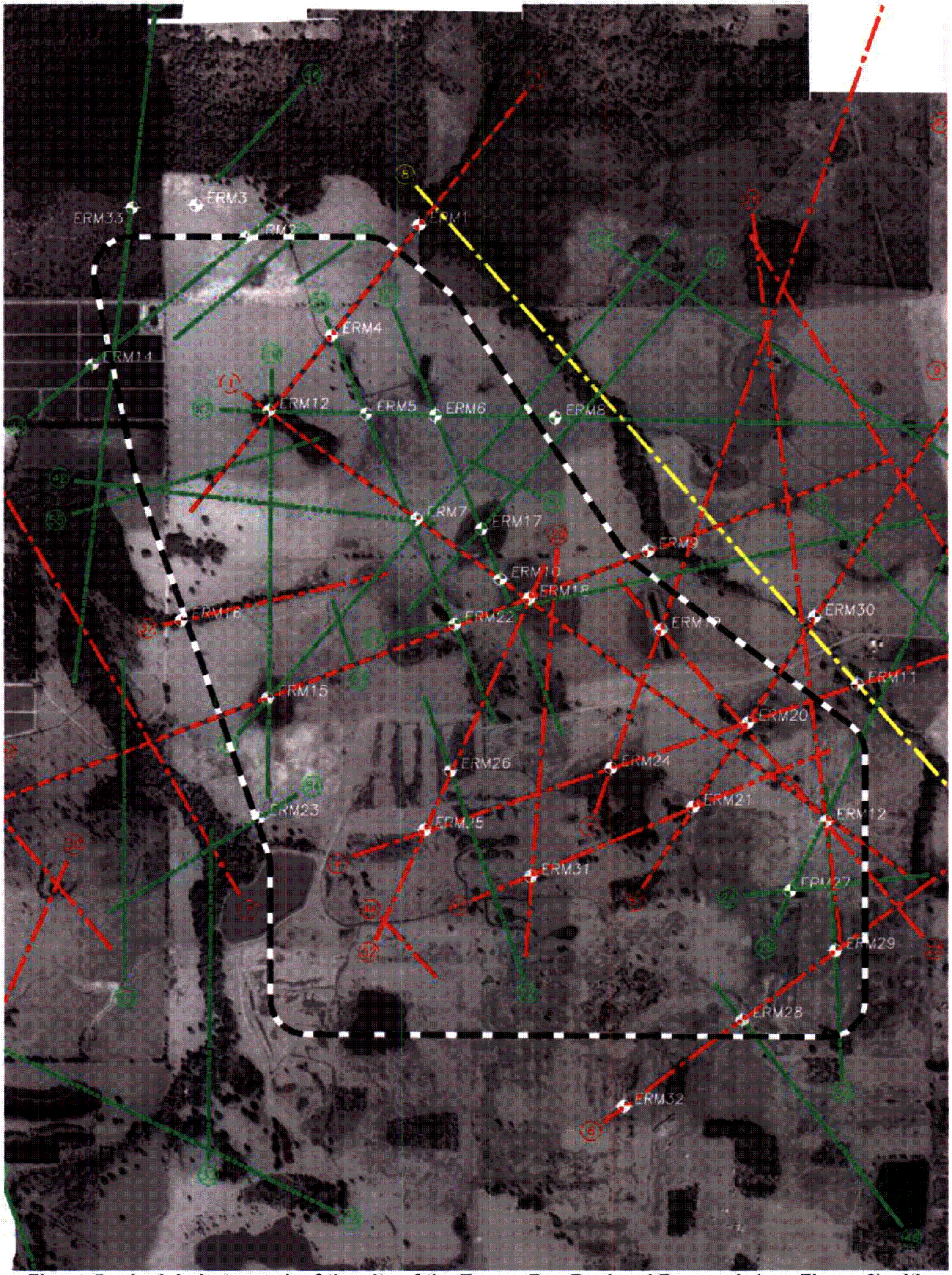

Figure 5 – Aerial photograph of the site of the Tampa Bay Regional Reservoir (see Figure 2) with photolineaments identified by colored lines. The color and pattern of the line indicates the level of confidence that can be placed on the photolineament.

often than not, a photolineament analysis is conducted and the assumption is made that linear features reflect fracture traces.

Ground Truthing of Fracture Traces and Photolineaments

SDII Global Corporation (SDII) recently completed an analysis of photolineaments at the Tama Bay Regional Reservoir (Figure 5). Prior to construction of the 1,100 acre reservoir, there were several circular features that might reflect sinkholes, as well other photolinear indications (Figure 5). SDII conducted a photolineament analysis and then "ground truthed" the photolineaments using ground penetrating radar, refraction and reflection seismic profiling, and standard penetration test drilling. Figure 5 shows the photolineament analysis and Figure 6 summarizes the outcomes of the ground truthing.

Clearly, there is considerable risk to the assumption that any photolineament represents a fracture trace. Over half of the 57 photolineaments identified at the reservoir (Figure 5) were not found to have a subsurface expression related to karst or fracturing.

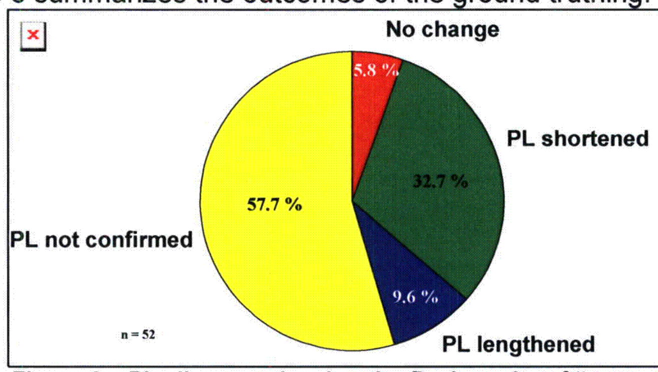

Figure 6 – Pie diagram showing the final results of "ground truthing" the photolineaments identified at the Tampa Bay Regional Reservoir. PL refers to photolineament. Note that almost 60% of the photolineaments could not be confirmed and that about 42% were either shortened or lengthened. Only about 6% of the photolineaments were confirmed as fracture traces without modification.

Causes of Fractures

Fractures are caused by many different processes, including stress release as a result of tectonic movement, tidal stresses, and other processes. For example, Figure 3 illustrates joints caused by material shrinkage (cooling of lava). Folding and faulting (tectonic movement) are not of great concern in Florida, but tidal stresses are. The fractures shown in Figure 1 were apparently caused by tidal stresses and then enlarged by groundwater dissolving the limestone of the fracture walls.

The solid earth is subjected to tidal stresses just like the oceans. Although we cannot feel them[1], earth soils, sediments and rocks and any associated structures are subject to flexing depending on the positions of the moon and sun. Every tidal cycle, the earth's crust flexes as much as 10 inches. This movement is associated with a broad, slow moving wave. The passing of the tidal cycle causes microscopic motions at the local scale. The earth tidal wave is so large that we cannot feel it and it has no significant short-term effect on small structures.

---

[1] Very precise measurements are required to detect earth tides, but they can be measured. They are measured with tiltmeters, gravity measurements, and even high-resolution geographic positioning systems (GPS).

A

Over time, however, this repetitive tidal movement and flexing can cause cracking. This is why SDII does not like to like to partially underpin structures. The tidal flexing combined with other movements (i.e., movements caused by water table elevation changes, expansive clay, thermal expansion and contraction, etc.) can cause differential movement and additional cracking in some structures. Normally, the structure moves as a unit, but partial underpinning may cause the un-pinned part of the structure to flex normally while the pinned part may not flex as freely.

B

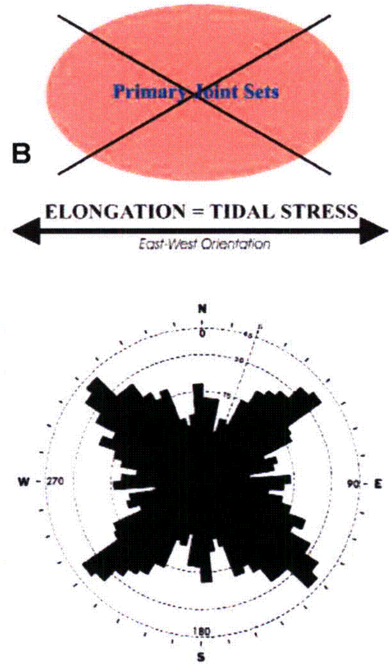

Figure 7 – Effects of tidal stresses on joint development in rocks of Florida. A – The strained ellipsoid. B – Rose diagram illustrating orientations of photolineaments at the Cross Bar Ranch, Pasco County, Florida.

The flexing takes place over millennia in soils, sediments, and rocks. As a result, fractures develop in materials that can lose cohesion or break over time. Figure 7A demonstrates the "strained ellipsoid" caused by flexing from right to left (east to west), as would be the case with tidal flexing. As the tidal cycle passes, the right hand side of the rock is subjected to the tide before the left. This differential movement causes the rock to break into two conjugate sets of fractures. One is oriented northeast-southwest and the other northwest-southeast (Figure 7B).

This bimodal pattern of photolinears is commonly encountered when a photolineament analysis is conducted on rocks that have been fractured by the tides. For example, Figure 7B is a rose diagram showing the frequency and orientations of photolineaments at a wellfield in Florida. Note the prominent conjugate sets of photolineaments and the smaller number of features exhibiting other orientations.

When conducting a photolineament analyses in Florida, you can expect this pattern with tidally induced fractures. There are instances of other orientations, such as the small north-south group shown in Figure 7B. These may be a result of ancient tectonic forces that caused faulting and folding in the pre-Tertiary basement rocks of Florida or they may reflect heterogeneities in local bedrock, or they may not reflect fracture traces at all. The Plant City Lineament (Figure 3) runs north-south and is associated with a basement fault that formed during the break-up of Pangaea (Culbreth, 1988).

One should never assume that photolineaments and/or fracture traces are associated with faulting in Florida. While some may reflect faulting, most reflect tidal flexing or are spurious (Figure 6). Some early Florida geological reports (i.e., Vernon, 1951) have argued that offsets in widely separated boreholes and the presence of slickensides in exposures as representing shallow faults in Florida's Tertiary strata. These alleged faults are highly controversial and have not been confirmed by more recent investigations.

There have been numerous studies that document faulting in the pre-Cretaceous strata of Florida. This faulting is associated with the break-up of Pangaea and passive continental margin development as sea-floor spreading opened the Atlantic Ocean and

Gulf of Mexico. Coleman (1979) and O'Conner (1984) are excellent examples of the works that depict these basement fault systems.

Culbreth (1988) has shown that ancient faults in the pre-Cretaceous strata of Florida can be expressed as photolineaments on the land surface. The tidal stresses and, perhaps, residual movement during the middle and late Tertiary have resulted in translation of fractures and possible minor faults into younger strata. For the most part, the movements appear to result in warping of strata rather than faulting, however. The fractures are also translated into unconsolidated strata because of

- Settlement of unconsolidated sediments into solution-enlarged fractures in the underlying, consolidated strata;
- Differential weathering, illuviation, or erosion caused by groundwater movement across karst surfaces;
- Differential consolidation of sediments into relict erosional features preserved in underlying unconformity surfaces, and
- Growth of vegetation in clay- or silt-rich, moisture-holding soils located over somewhat deeper bedrock features associated with fractures.

Photolineament Analysis Method

Photolineament Indicators – As noted above, photolineaments are identified by alignments of a number of different indicators on aerial photographs, satellite images, and/or topographic maps, including

- Alignments of 3 or more closed depressions, wetlands, or lakes;
- Linear stream segments;
- Linear soil tonal differences (low areas are often darker because soils are wetter in the fracture);
- Alignments of vegetation, especially wetland vegetation; and
- Elongation of depressions, wetlands, and lakes.

It is best to utilize multiple images for the analysis. Utilize historic aerial photographs where the amount of cultural "clutter" (roads, paved areas, disturbed areas, buildings, etc.) can be minimized. A good source of historic aerials in Florida is http://palmm.fcla.edu/, the State Universities of Florida collection. Follow the links to the aerial photograph collection. Also, satellite images are very useful for large features. Google Earth is a good source of satellite images for this purpose.

Look for images with good resolution and contrast because it will be necessary to be able to identify the indicators noted above. If the image is digital, it may be helpful to use a good image editing program to enhance the contrast and brightness of the image.

Topographic maps are useful for [photo] lineament delineation. Obviously, use of soil tonal differences and vegetation-related indicators is not possible, but alignments of depressions, wetlands, and lakes can be easier to identify on a topographic map than on an aerial photograph. If possible, 1:24,000 scale maps are preferred, and older versions of the maps are better than updated ones because of the changes caused by development.

Viewing the Image or Map - Study the maps and images carefully before delineating anything. It is helpful to look at the images at a low angle and well as straight on. Low angle viewing often helps identify alignments. Also rotate the image or map (or walk around it) in order to study all possible orientations.

Table 1 – Sample Photolineament Confidence Ranking Matrix.

	Indicators (s = strong indicator, m = moderate, w = weak indicator)					**Confidence Level**
Photolinear Number	**Alignments of 3 or more closed depressions, wetlands, or lakes**	**Linear stream segments**	**Linear soil tonal differences (low areas are often darker because soils are wetter);**	**Alignments of vegetation, especially wetland vegetation;**	**Elongation of depressions, wetlands, and lakes**	**(3 = low, 2 = moderate, 1 = high)**
1	s	s			m	1
2	w					3
3	m		w	m	m	1
4	m				m	2
5			m	w		3

Once you are comfortable with the image, you are ready to mark it up. Always create a working copy or an overlay to mark on. Never mark up the original because you will inevitably want to change something. Preferably, use a digital image and image editing software to mark the image up. This alternative gives maximum flexibility.

Confidence Ranking - Each photolinear is identified by recognition of some, or all, of the indicators listed above (Table 1). Clearly, you will have more confidence in some photolinears than others because of the strengths of the indicators and the presence of multiple indicators. SDII ranks the photolinears based on the level of confidence based on the indicators. The attached table is the Confidence Ranking Matrix used for this purpose.

As indicated by the photolineaments identified in Figures 5 and 8, each photolinear is numbered and assigned a confidence level. You can use different colors, line types, or both on the map or image.

The level of confidence depends on the number of indicators, number of occurrences of a single indicator, and the strengths of the indicator (i.e., subtle or very obvious). The simplest ranking system that seems to work is to note that the indicator was weak (w), moderate (m), or strong (s) in the indicator column. Other notations are acceptable. The right-hand column is the final ranking, which ranges from 3 (low) to 1 (high) level of confidence. Table 1 illustrates a Confidence Ranking Matrix filled out for a few sample photolineaments. The matrix is subjective, but should help prioritize areas where fractures most likely occur.

Map Preparation - The final map should show the locations and confidence levels of each photolineament preferably superimposed on an aerial photograph or suitable base map. Figure 5 shows a photolinear map superimposed on an aerial photograph.

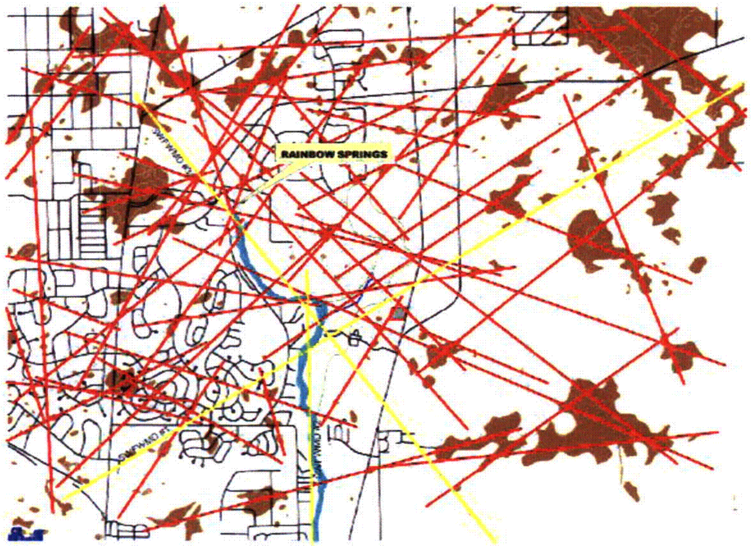

Figure 8 – Photolineament map superimposed on a GIS-based topographic map. Yellow lines are low confidence, red are high. Dark brown areas are closed depressions that apparently reflect sinkholes and other karst features.

Figure 8 illustrates a photolinear map superimposed on a GIS-based topographic map. Elongations of closed depressions and alignments of depressions were major indicators of these photolinears. Note also the northeast-southwest and northwest-southeast photolinear sets, which align with the principal fracture orientations suggested by the strained ellipsoid (Figure 7).

It is important to understand that most fractures large enough to map consist of sets of smaller fractures. Therefore, they are typically 10s to 100s of feet in width. We draw lines on a map or image to roughly represent the central axis of the proposed fracture, but, if the fracture exists, it is typically much wider than the line. This is suggested by the widths of the closed depressions (sinkholes?) in Figure 8. The actual fractures, if present, are likely to be much closer to the widths of the depressions than the lines.

Use of the Photolinear Maps

The photolinear maps are indicators, *not proof*, of fractures. Given the uncertainty inherent in this assumption and the quality of the data used to prepare the map, the map is interpreted as follows:

- Fractures may exist in the locations indicated;
- Not all of the photolinears reflect fractures;
- There are probably fractures present that were not identified by photolinear analysis;
- Groundwater may preferentially flow along the photolinear alignments;
- Photolinear intersections may be excellent places to develop water supplies (i.e., wellfields);
- Closed depressions may, or may not, reflect ancient sinkholes;
- Sinkhole risk may be greater along the alignments that between them and greatest near intersections;

- □ Photolinears may represent areas of enhanced recharge and photolineament intersections may reflect areas of greatest recharge; and
- □ Ground truthing is required to confirm the presence of fractures and related features, such as depressions sinkholes.

Ground Truthing Method

Ground truthing of photolinears is complicated and requires some sophistication. If there are many photolinears on the map, a random sample or selection based on confidence may be necessary to reduce the amount of field testing required. Investigation of a subset of photolinears introduces considerable uncertainty as to overall risk, however. Remember the Tampa Bay Regional Reservoir ground truthing where all intersections were drilled and multiple geophysical methods were used to identify fractures? After all that work, many photolinears were found to not represent fractures and others were mischaracterized to some degree (Figure 6).

Methods that have been utilized to ground truth photolinears include:

- □ Direct field examination of the rock;
- □ Excavation of overburden with a backhoe or other excavation equipment;
- □ Drilling (auger borings, standard penetration tests, cone penetrometer soundings, coring, etc.)
- □ Geophysical exploration (ground penetrating radar, microgravity, seismic reflection and/or refraction, spontaneous potentials, electrical resistivity, etc.)
- □ Examination of rock or sediment exposures; and
- □ Probing.

Summary

Photolineament analysis is a powerful triage tool for evaluating sinkhole risk, groundwater availability, mineral deposits, and other applications. However, it is important to understand the uncertainties associated with the method. Without ground truthing, one can only offer an educated guess as to the presence of fractures based on photolinear analysis.

Some of the uncertainty can be reduced by using the confidence ranking system proposed in this document.

In the absence of ground truth to confirm the presence of fractures, it is very important to keep the uncertainties in mind and communicate them in reports and meetings with colleagues and clients.

References Cited

Coleman, N.M., 1979. Gravity Investigation of Basement Structure in Northwest Peninsular Florida. Thesis (M.S.), University of South Florida.

Culbreth, M.A., 1988. Geophysical Investigation of Lineaments in South Florida.

Masters Thesis, University of South Florida, Tampa, 97 p.

Lattman, L.H., 1958. Technique of mapping geologic fracture traces and lineaments on aerial photographs. Photogrammetric Engineering, 24:568-576.

Lattman, L.H., and R.H. Matzke, 1961. Geological significance of fracture traces. Photogrammetric Engineering, 27:435-438.

Lattman, L.H., and R.R. Parizek, 1964. Relationship between fracture traces and the occurrence of groundwater in carbonate rocks. Journal of Hydrology, 2:73-91.

Littlefield, J.R., M.A. Culbreth, S.B. Upchurch, and M.T. Stewart, 1984. Relationship of modern sinkhole development to large-scale photolinear features. In B.F. Beck (ed.), Sinkholes: Their Geology, Engineering & Environmental Impact. Rotterdam, B.A. Balkema, pp. 189-195.

O'Conner, L.D., 1984. Gravity Study of Crustal Structures in Northeast Peninsular Florida. Thesis (M.A.), University of South Florida, Tampa, Florida.

Vernon, R.O., 1951. Geology of Citrus and Levy Counties, Florida. Florida Geological Survey, Bulletin No. 33, 256 p.

PHOTOLINEAMENT CONFIDENCE RANKING MATRIX

Photolinear Number	Indicators (s = strong indicator, m = moderate, w = weak indicator)					Confidence Level
	Alignments of 3 or more closed depressions, wetlands, or lakes	Linear stream segments	Linear soil tonal differences (low areas are often darker because soils are wetter);	Alignments of vegetation, especially wetland vegetation;	Elongation of depressions, wetlands, and lakes	(3 = low, 2 = moderate, 1 = high)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						
35						
36						