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C. Renee Sparks
crs38@calvin.edu

Issac J. Jacques
Calvin University

Cheryl L. Verbree
Calvin University

Thomas J. Timmermans
Calvin University

Stuart Dykstra
Calvin University

CHARACTERIZATION OF SURFACE GEOLOGY AND HYDROGEOLOGY IN THE UPPER ULUA RIVER BASIN, HONDURAS

C. Renee Sparks, Issac J. Jacques, Cheryl L. Verbree, Thomas J. Timmermans, and Stuart Dykstra
Calvin University
3201 Burton St. SE
Grand Rapids, MI 49546 USA
crs38@calvin.edu

ABSTRACT

This research includes a hydrogeologic assessment in and around La Union, Honduras to determine the contribution of groundwater to the surface water system and understand the geological control of groundwater storage and movement. Field methods were employed and focused on spring characterization, geochemical signatures, and structural data. Field data was gathered, and locations determined using cellular-integrated GPS signal and the Fulcrum mapping software mobile application. During the summer of 2017, data on 111 geologic points and 34 water points were collected to understand the hydrogeology of the region. Streams and springs were monitored for pH, flow characteristics and conductance as a measure of total-dissolved-solids (TDS). TDS ranged from 22.6 to 485 mg/L with higher values indicating groundwater influx into the surface system. In comparison, lower TDS values are attributed to runoff. Structural information was collected using a Brunton transit compass for strike and dip of lithologic contacts. Structural trends include strikes around 240 degrees, dip direction and approximate magnitudes at 330 and 40 degrees, respectively. Geologic data indicate significant structural deformation, supportive of tectonic activity in the region. For many of the springs in this area, the data can be used to interpret that water is stored in the Jaitique Formation as a perched aquifer controlled by stratigraphy and structure. The groundwater moves down dip through secondary porosity in the Jaitique Formation until it comes into contact with the Lower Valle de Angeles. This Lower Valle de Angeles unit acts as an aquiclude preventing percolation into the ground and resulting in springs at the surface.

KEY WORDS: Ground Water, Hydrogeology, Honduras

INTRODUCTION

Development and understanding of groundwater resources in Western and Central Honduras has been minimal outside of localized alluvial aquifers along major rivers. As a result, there is limited knowledge on the capacity of stratigraphic aquifers and even less known about the groundwater flow between these aquifers. The structurally complex region of Western and Central Honduras requires an integrated hydrogeologic approach to understand the flow of meteoric water into the groundwater system and the discharge of groundwater to the surface system. This geologic region, often referred to as the Chortis crustal block (Case et al. 1990; Donnelly et al. 1990), consists of metamorphic rock overlain by a sequence of sedimentary and volcanic units up through the Cretaceous time period (Rogers, 2003).

The purpose of this investigation is to obtain hydrogeologic, geochemical, and structural data in the study area to develop a conceptual model for groundwater flow and discharge. This study focuses on the village of Chimizal and the area around La Union approximately 150 km northwest of Tegucigalpa (Figure 1). Communities in this area use springs and the associated surface water for drinking, cleaning, and coffee processing. However, little is known about these springs, their capacity, quality, or relationship to surface water and geology. In addition, some of these springs are seasonal and do not flow during the dry times of the year.

This investigation requires a thorough working knowledge of the local stratigraphy. Stratigraphic aquifers and aquitards govern the recharge into, flow through, and discharge of groundwater based on porosity and permeability of the rock type. Since these are the primary controlling factors, a detailed examination of the stratigraphic column is pertinent to this study.

Stratigraphic units in Central and Western Honduras include Paleozoic basement rocks that have been metamorphosed, sedimentary units of Mesozoic ages, volcanic units of Mesozoic and Cenozoic ages, and sedimentary units of Cenozoic age. The

Cacaguapa Group is the oldest unit found in the central Chortis block. It is a poorly known metamorphic basement from the Paleozoic or older (Gose and Finch 1992). For the purposes of groundwater movement in this region, these basement rocks are considered to be relatively impermeable acting as the base aquitard of the study area. Though not exposed in the study area, the Agua Fria formation is interpreted at depth as overlying the metamorphic basement rocks in Central Honduras (Rogers et al. 2007). The Agua Fria formation occurs as a massive quartz pebble conglomerate with thick sections of shale and siltstone, sandstone, and minor coal-bearing strata (Gose and Finch 1992). As implied by its name, this unit serves as a lower aquifer in the stratigraphic sequence.

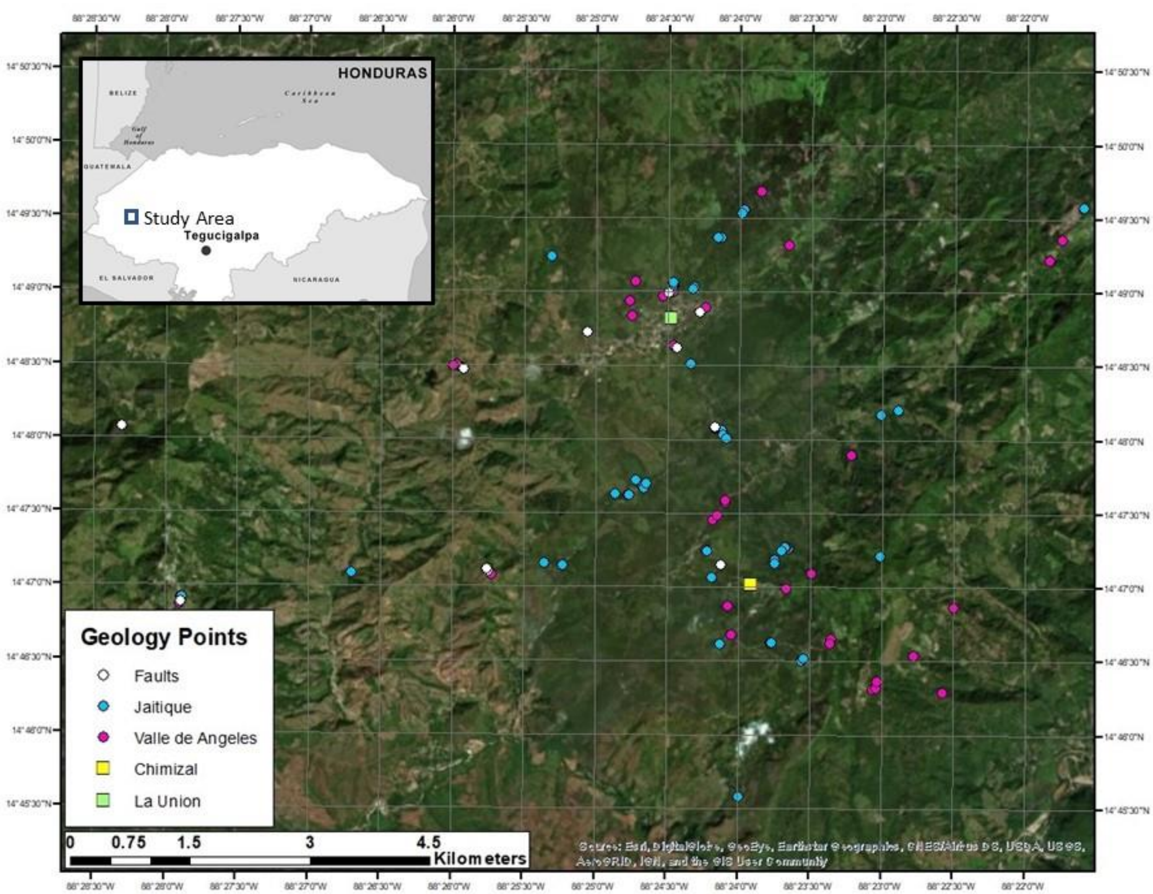

Figure 1. Geographic location of study area within Honduras relative to the capitol, Tegucigalpa.

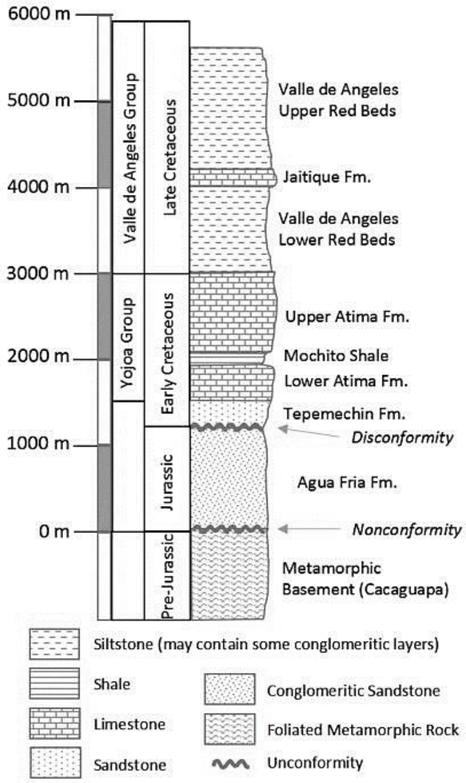

Figure 2. Stratigraphic column of sedimentary units in Central Honduras (after Rogers et al. 2007)

According to Rogers and others (2007), a disconformity separates the Agua Fria formation from Early Cretaceous units of the Tepemechin Formation and Yojoa Group (Figure 2). Both of these units also act as stratigraphic aquifers. The Yojoa group is subdivided into upper and lower Atima formations by the Mochito shale (Rogers et al. 2007) recognizable in the field based on its green color and fine-grained texture (Finch 1981). Volcanic and pyroclastic rocks also occur within the upper and lower Atima formations (Rogers et al. 2007) serving as local aquitards within the larger aquifer. The upper Atima formation is a gray, fossiliferous limestone with occasional mudstone intervals and exhibits varied bedding scales from massive to 10-20 cm (Rogers 2003). The Atima formation is exposed in the southeast side of the study area and serves as an interface between groundwater and surface water of the Rio Palaja according to the geologic map of the area (Kozuch 1989).

Much of the geology exposed in Western Honduras consists of the Valle de Angeles Group. This group is split into Upper and Lower red beds divided by the Jaitique Formation and occurs stratigraphically above the Atima formation. The Lower Valle de Angeles Formation consists of terrigenous redbeds that are clay rich and contain a few lithic conglomeratic layers. Pebble lithologies within the conglomerate layers include schist, limestone, andesite, and red sandstone (Rogers et al., 2007). This lower unit can have thicknesses up to 1000 m (Gose and Finch 1992). The lower red beds of the Valle de Angeles consist of breccia, shale, siltstone, and sandstone with deposits attaining a maximum thickness of 450 meters (Rogers 2003; Gose and Finch 1992). The upper red beds are mainly fine-grained red shales and siltstones (Gose and Finch 1992). The upper reds grade from the lower reds (Scott and Finch 1999). As a whole, the Valle de Angeles Group acts as an aquitard. Due to its stratigraphic occurrence, this unit produces perched aquifers in some areas and confined aquifers in others.

Though the Jaitique formation is included in the Valle de Angeles Group, it serves as a localized carbonate aquifer in the study area. This formation includes two units: an unnamed cliff-forming limestone member overlain by a thin petroliferous limestone designated the Guare Member (Scott and Finch 1999). The lower member is about 100-150 m thick, comprised of thick-bedded shelf limestone, well-dated paleontologically as Cenomanian (Scott and Finch 1999). This thick carbonate unit serves as a local aquifer and contains secondary porosity related to bedding planes and joint sets produced during structural deformation.

Regional and local stratigraphic units have been subjected to multiple tectonic events related to the interaction between major crustal plates in and around the Caribbean (Burkart and Self, 1985). Brittle and ductile deformation associated with these tectonic events are evident in the remaining structures preserved in the stratigraphic units (Aldrich et al. 1991). Larger-scale structures have been mapped throughout the region with numerous normal and strike-slip faults in the central part of the Chortis terrane produced by trans-tensional stresses (Burkart and Self 1985). The northern and southern margins of the Chortis crustal terrane are bound by fold and thrust belts supported by geophysical evidence (Case et al. 1990). The study area is dominated by listric, normal faults due to trans-tensional stress and deformation (Barberi et al. 2013; Burkart and Self 1985).

METHODS

Field investigations were conducted over an area of approximately 3000 km2 of La Union, Lempira Department, Honduras. High resolution sampling and investigation focused on the village of Chimizal, located approximately 4 km to the southeast of La Union. Latitude and longitude of hydrologic and geologic features were obtained using the Fulcrum mapping application.

Prior to conducting field investigations, spatial and temporal data sets were collected and evaluated to establish a baseline understanding of the topography, associated geology, hydrogeology, and land use practices. Base maps were created using ESRI's ArcMap GIS software with U.S. Geological Survey surface data for the geology of the Caribbean (French and Schenk 2004). Digital Elevation Model (DEM) data in this area is very important for understanding the relationship between the surface location and the associated geologic units exposed at that location. These base maps were exported and opened in the program TileMill for conversion into MBTiles format for use with the Fulcrum mapping mobile application. The Fulcrum mapping application utilizes a cellular GPS signal to triangulate for location.

The geologic map for this area (Kozuch 1989) was obtained as an electronic image and geo-rectified to the digital elevation model data in ArcMap. Methods associated with the use of this geologic map include the recognition of normal faults by up-thrown and down-thrown blocks, stratigraphic contacts, as well as strike and dip data. Lithologic thickness ranges along with stratigraphic dip and structural features are somewhat limited in the study area but provide a starting point for data collection and initial interpretations.

Prior to data collection, the Fulcrum input form was customized to include sections for characteristics of interest for geological units and water sources. Field data was gathered, and locations determined using cellular GPS signal and the Fulcrum mobile app. Outcroppings of geological units were observed for characteristics such as colour, estimated relative porosity, bedding and structural information of strike and dip magnitude as described by Lahee (1961). Structural data on rock characteristics were recorded using a Brunton transit compass, as described by Coe et al. (2010). Water geochemistry was measured using a calibrated PCSTestr 35 Oakton Waterproof Multi-Parameter Tester. Groundwater presence can be detected by monitoring spring and streams for pH (Drever 1997) and total dissolved solids (Faure 1998). Springs and streams were monitored for pH, TDS calculated from conductivity, and temperature. Spring locations provide clues to the subsurface lithology while geochemistry can indicate groundwater residence.

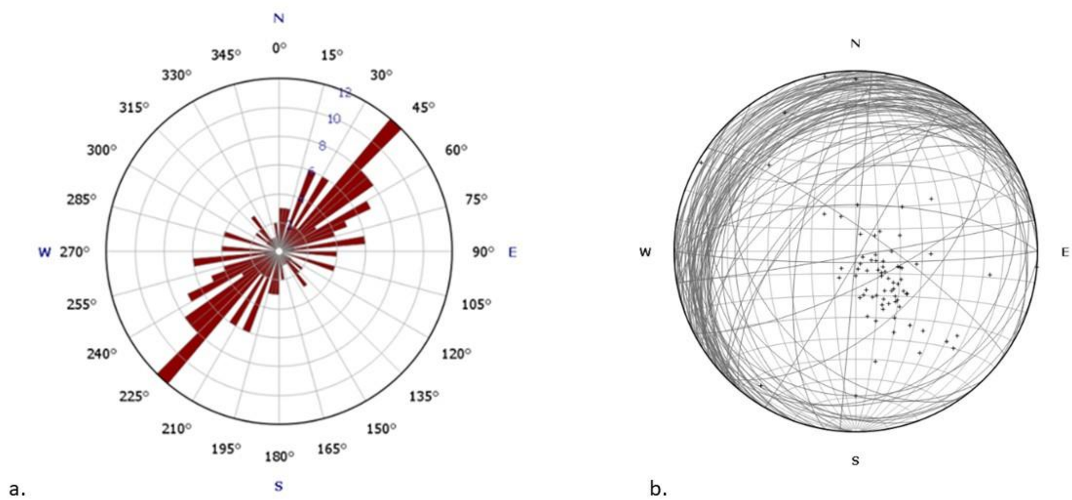

Figure 3. Structural data plotted as a. Strike orientation and b. Planar dip and pole point data for stratigraphic bedding surfaces and contacts.

RESULTS

Geologic Data

Two main units were encountered in the field: the Valle de Angeles formation, as a purple-red siliciclastic unit, and Jaitique, which typically occurs as a cliff forming unit. The Valle de Angeles (lKva and uKva) is a fine-grained siliciclastic unit that appears to exhibit low porosity based on spring occurrence. This unit exhibits a variety of strike and dip measurements due to folding and internal deformation associated with a reduced level of structural competence. Comparatively, the Jaitique formation had a high secondary porosity as fracture sets. In some locations, limestone units were hydrothermally altered. Some locations exhibited evidence of compressional events. The Valle de Angeles was not observed to exhibit much porosity or jointing since it included fine grained members and was deeply weathered. The Jaitique formation exhibited low primary porosity, but high secondary porosity. In some areas the limestone unit was thinly bedded and in others it occurred as massive and karsted.

Field data included 111 geologic points in which strike, dip direction, and dip magnitude were recorded for stratigraphic units and structural features. This data is provided in Table 1. When plotted, structural trends include a cluster of strikes around 240 degrees, dip direction of 330 and average magnitudes of 31 degrees (Figure 3).

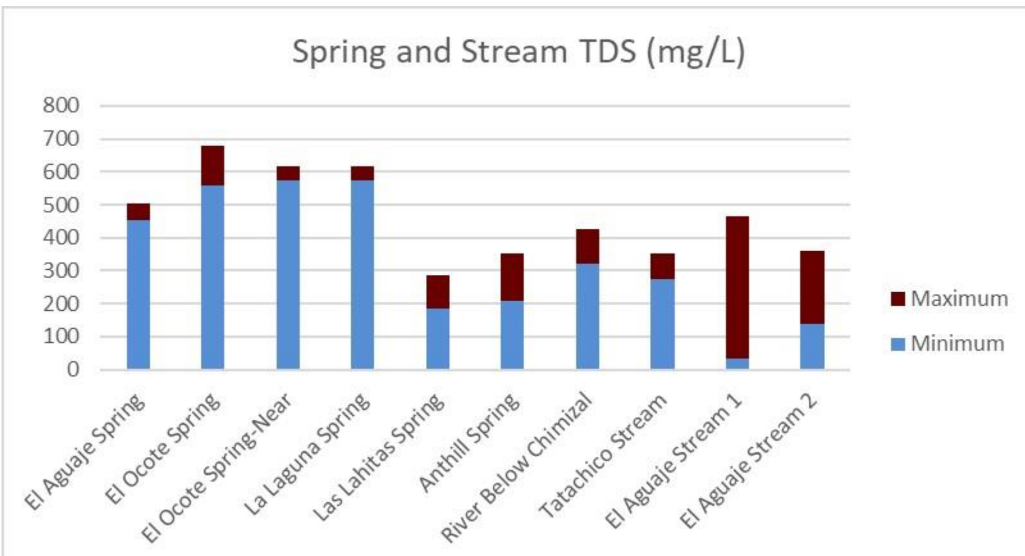

Figure 4. Geochemical data for total dissolved solids as a function of conductivity.

Geochemical Data

Geochemical parameters measured each week at locally identified springs, adjacent streams, and larger streams included pH, specific conductance, and temperature. The results are given in Table 2. There was a significant difference for specific conductance (p value = 0.001) between springs and streams with an average of 402 μS/cm for streams and an average of 252 μS/cm. However, no significant difference for temperature was observed between springs and streams. In general, springs have a lower temperature and higher specific conductance signature than streams. Total dissolved solids for water point data ranged from 32 to 680 mg/L with higher conductivity values indicating groundwater influx into the surface water system (Figure 4). In comparison, water points with lower conductivity, calculated TDS and pH are attributed to runoff from rainfall events. Springs averaged 207 mg/L while streams averaged only 135 mg/L.

DISCUSSION

Data from this study along with previously published information support a stratigraphic and structural interpretation of the geology in the area that influences the hydrogeology. When considering the stratigraphic and structural data, it is evident that there are several structural blocks separated by normal, reverse, or strike-slip faulting and many of these blocks are tilted and rotated. Field data indicate outcrops strike to the southwest at around 240 degrees with an average dip of 31.1 degrees to the northwest. This is supported by observing the elevations of the contact between the Atima formation and lower Valle de Angeles formation. To the north, the contact occurs at 900 meters; along the mountain, the contact occurs at 1100 meters and approximately 14 km to the southeast of La Union, the contact occurs at 900 m resulting in an overall dip to the northwest.

Springs often occur at the base of the Jaitique Limestone where it outcrops along the sloping side of the mountain. Based on the geological data, it is our interpretation that water collects in the Jaitique formation on top of the mountain and flows northwest down dip. The water flows through the fractured, and in some cases, karsted Jaitique Limestone, and occurs as springs where the unit is in contact with the lower Valle de Angeles. This is supported by the high conductivity values of the spring water and the springs being located along the contact. The Lower Valle de Angeles is interpreted as having low permeability and serving as an aquiclude preventing percolation into the ground and resulting in a spring at the surface.

Stream geochemistry concurs with Faure (1998) that streams close to the equator exhibit low total dissolved solids. Streams were often recorded to have relatively low total dissolved solids during precipitation events. When the weather was dry, streams would lose much of their flow but exhibit higher total dissolved solids, which we interpret to mean there is a component of groundwater in the streams. Spring geochemistry exhibited statistically higher conductivity values which ranged between 490-680 mg/L. Although pH was expected to be higher from springs because they flow through limestone, there was no statistical difference between spring and stream pH. The lack of significance in pH between streams and springs is likely due to the Valle de Angeles being calcic. Outcrop data indicates the Valle de Angeles regularly effervesced when exposed to HCl which means the streams will have increased amounts of Ca2+ and HCO3- ions (Drever, 1997).

CONCLUSIONS

Stratigraphic units are tilted in the study area most likely due to tectonic uplift during the Late Cretaceous to Early Tertiary. These units have experienced structural deformation as faults and folding. Because of continued tectonic activity during Quaternary extension, structural blocks experienced movement along faults as well as dextral rotation. Stratigraphic dip associated with this structural deformation influences groundwater flow along fracture systems, bedding planes and stratigraphic contacts. Temporary groundwater storage occurs in the Jaitique Limestone and can be recognized at springs and in surface flow by the total dissolved solids accumulated in the groundwater system. This groundwater tends to flow down dip unit in contact with a fault or unit of lower permeability. Valle de Angeles units exhibit lower permeability and act as aquicludes preventing percolation into the ground and resulting in a spring at the surface when in contact with the Jaitique above. Limestone units may serve as aquifers to a depth where fractures are filled with mineralization reducing secondary porosity and permeability.

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