RU_CAGeochem, a database and sample repository for Central American volcanic rocks at Rutgers University

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The Rutgers University Central American geochemical dataset focuses on the active volcanoes related to the Cocos-Caribbean convergent plate boundary that extends from Guatemala to Costa Rica in Central America. The RU prefix signifies that the data and samples are primarily from the long-term Central American research project started at Dartmouth College in 1970 and continued at Rutgers University from 1974 to the present. The database is decidedly uneven because of the impressive improvement of analytical techniques over the span of data collection. Further complications arose because most of the sampling and analysis were part of the educational process for many different undergraduate and graduate students using different types of instruments. This note presents, as a reasonably coherent whole, geochemical data and metadata for about 1400 samples collected by at least 40 students and colleagues. Many unpublished Sr, Nd, and Pb isotopic ratios are included here but most of the new data are metadata that provide greatly improved descriptions of the tectonic settings, locations, and status of the samples as well as estimates of data quality.

1. Background

Richard E. Stoiber, a mining geologist at Dartmouth College, travelled to Central America in the 1960s to study the ore-forming process at active volcanoes. This initiative created a vibrant volcanology programme, based on wide-ranging field and lab studies of active volcanoes. Carr and Rose (1987) presented CENTAM, a database of Central American volcanic rocks, in a volume celebrating Stoiber's 75th birthday. Three motivations initiated this data project. First, many recent analyses of Central American volcanics were in MS and PhD theses but not in the published literature because some editors wanted just a few representative examples. Second, the National Science Foundation (NSF) paid for the sampling and analysis so the results should be publicly available. Third, we wanted to be in the forefront of the computer revolution that was making it easy to share data. The Rutgers University Central American geochemical dataset (RU_CAGeochem) is an evolution of CENTAM but has much less coverage of central and western Guatemala.
because most sampling in this area was accomplished by Rose’s students from Michigan Technological University.

2. Availability of data and sample splits
The Central American collection at Rutgers has been available to the geoscience community since before the publication of CENTAM. In 1985, sample splits were provided to the $^{10}$Be group at the Department of Terrestrial Magnetism. The resulting publication (Tera et al., 1986) proposed that $^{10}$Be can trace subducted sediment through the arc-volcanic system to eruption. This success, achieved by cooperatively providing samples to peer researchers without conditions, encouraged Carr and Rose to do so on a broader scale. The purpose behind open access to sample splits was to increase interest in research on Central American volcanoes. This approach has proven highly successful. Many elite labs requested splits for measurement of relatively exotic elements or isotopes. Some of the data obtained on our splits have been added to RU_CAGeochem. However, we have not meticulously included every analysis made. For example, the Cl isotopic ratios of Barnes et al. (2009) are not included.

Providing splits to peer researchers has greatly enriched the understanding of Central American volcanoes. The systematic investigation of Be and $^{10}$Be in Central America (Tera et al., 1986; Morris et al., 1990; Reagan et al., 1994), made a convincing argument for transfer of $^{10}$Be from the uppermost subducted sediments to the active volcanoes, providing direct evidence of element recycling during the subduction process. Most of the samples selected for Be isotopic study had a full set of trace element data and Sr and Nd isotopes. However, the short half-life of $^{10}$Be requires young samples and so most were from historic flows. B data were added to many of the same samples (Leeman et al., 1994). Chalcophile elements were the focus of research by Noll et al. (1996). Iodine isotopic data were obtained by Snyder and Fehn (2002). Chan et al. (1999) added Li isotope analyses. Eiler et al. (2005) added O-isotope measurements of olivine and plagioclase phenocrysts that strongly implied a significant role for serpentine in Central American magmasenesis. Although this is not a comprehensive list of geochemical data obtained on the RU_CAGeochem samples, it does show the value of an open sample policy.

As the database grew, the Rutgers group added the additional goal of making it geographically comprehensive, collecting samples from as many recent volcanoes as possible, essentially attempting to fill in all the blank areas on the map. Two biases guided the sample collection. First, we sampled the active volcanic front and only the most recent back-arc volcanoes with the goal of better understanding the ongoing processes. Second, the cores of mafic flows were sampled to reduce the effects of weathering and to find basalts that could provide the best control on mantle processes. Therefore, except for Arenal volcano, there are few tephra samples. Similarly, more silicic flows are under-represented. Representative mafic samples were selected for a full set of trace element and isotopic measurements. This data assembly allowed the geochemical description of an entire active volcanic front, providing a superior perspective for arc study (Figure 1). The regional geochemical variations revealed by the young mafic samples helped make Central America a focus area for the NSF Margins Subduction Factory.

3. Results
The most significant result from the comprehensive dataset was the discovery of geographical variations in elemental and isotopic ratios (e.g. Ba/La, $^{10}$Be/$^{9}$Be, U/Th) that trace material from the subducted plate through the mantle and to the volcanic front (e.g., Figure 1). These tracers reach maxima in Nicaragua and
decrease asymmetrically outward to the NW and SE. The influx of elements primarily derived from subducted sediment (e.g. $^{10}$Be, Ba and U) is approximately constant along the margin. The variation occurs in less fluid mobile elements, Th, La, Yb, etc., that vary primarily because of different degrees of melting. To first order, the regional pattern is a correlation between slab tracers (ratios) and the degree of melting. A tectonic factor that mimics this regional variation is dip of the subducted slab. In 1990, we proposed that areas of steeper dip allow the constant slab flux to focus into smaller volumes as it rises through the mantle wedge creating higher degrees of melting and higher ratios for Ba/La, U/Th etc. (Carr et al., 1990). However, this hypothesis is wrong in central and southern Costa Rica where the geochemistry is dominated by an input from the Galapagos hotspot, either from the mantle (Feigenson et al., 2004) or from the subduction of volcanic debris shed off seamounts that originated near the Galapagos hot spot (Hoernle et al., 2008; Gazel et al., 2009).

4. Development of RU_CAGeochem

CENTAM (Carr & Rose, 1987) included data from the literature as well as analyses from the collections of W. I. Rose and M. J. Carr. At that time the database was primarily of major elements, minor elements, and a few of the abundant trace elements. There were two major data sources, XRF from Michigan Technological University (by W. I. Rose Jr. and students) and DC-plasma atomic emission spectroscopy (DCP-AES) from Rutgers University (M. J. Carr and students). Over time, the database dropped most whole rock data not from Rutgers labs to provide greater uniformity. Furthermore, the RU prefix signifies that the database is primarily for samples and splits in the Rutgers University collection.

The addition of Sr and Nd isotopic ratios significantly upgraded the dataset (Feigenson & Carr, 1986). Another change was the addition of rare earth element (REE) measurements obtained via DCP-AES at Rutgers (Carr et al., 1990). However, most of these REE data were subsequently upgraded after ICP-MS instruments became available. By 2000, L. Patino completed a comprehensive geochemical survey of Central American volcanics using a quadrupole ICP-MS (Patino et al., 1997, 2000) for REEs and other trace elements. She also added a large number of Sr and Nd isotopic measurements. Pb isotopic ratios were added by Feigenson et al. (2004).

Two new labs led to significant recent upgrades in the data; a high resolution inductively coupled plasma mass spectrometer (HR-ICP-MS) lab for trace elements and a noble gas mass spectrometer for $^{40}$Ar/$^{39}$Ar age determinations. The data from these labs (Alvarado et al., 2006; Carr et al., 2007; Bolge et al., 2009; Gazel et al., 2009) comprise the great majority of high-quality data in the file.

5. Metadata

There are over 110 columns in RU_CAGeochem. About half are for geochemical data, such as isotopic ratios and chemical concentrations in weight% or ppm. The other columns are metadata divided into four groupings. The first 20 columns contain basic descriptions of the sample, such as the country of origin, the sample name, IGSN (International GeoSample Number), collector, current location of the samples, etc. The first column is an index that allows reconstruction of the original order if the sheet is sorted to find extreme values (e.g. the highest MgO contents). An integer column, Kcode, is a key to geographical subdivisions within the data. For example, a Kcode of 8 identifies samples from the Guatemalan volcanic front. The different Kcodes are explained in the tab called: RU_CAGeochem Notes, starting at row 65. A second integer column, Lcode, is a key to stratigraphic/geologic subdivisions within a single volcanic centre. Lcodes have not yet been included for all the volcanic centres. To the right of Lcode is Unit, which is the alphanumeric description that matches the Lcode. Next is relative position, a number graded so that the upper, younger material is highest. This facilitates stratigraphic plots.

Perhaps the most important addition is the column labelled Data Quality. This integer is an attempt to assess quality, with higher values for more complete and better determined analyses. Many samples, graded at 5, have just major elements and a few minor and trace elements. These data are appropriate to use for regional surveys involving major elements, such as Plank and Langmuir (1988). Most trace element data are from ICP-MS instruments but unfortunately they are variable in quality. Many measurements remain from ICP-MS instruments that were less capable than modern ones. The reasons for the quality grades are listed in the tab, RU_CAGeochem Notes, starting at row 100. For regional comparisons of trace element ratios, it is best to restrict the comparisons to the highest quality data, 20 and above. For Nb and Ta, a data quality of 35 should be used.

Location metadata occupy 13 columns. Although latitude and longitude should suffice, the maps available in Central America use a 1 km Universal Transverse Mercator (UTM) grid (Guatemala, Honduras and Nicaragua) or a 1 km Lambert grid (El Salvador and Costa Rica). Therefore, quadrangle name and grid coordinates are very practical and are the most accurate geographical data for RU_CAGeochem. With GPS it is now possible to obtain more accurate locations, but there are difficulties even for those countries that use the UTM grid. Most Central American quadrangle maps are based on the Clarke ellipsoid of 1886 and the North American datum of 1927, whereas the default base for the GPS system is WGS84. Because this is also the base for the very useful Google Earth program, it is worthwhile to record latitude and longitude using this datum. The difference between the
two reference systems is primarily a shift of about 200 m North by the WGS datum. The Lambert projections used for the topographical maps of El Salvador and Costa Rica use the Ocotepeque datum. The translations of map grid to latitude and longitude are not well done for these two countries.

At least half of the samples were initially located on maps with the aid of an altimeter and compass and later were converted to digital form. The location errors for these samples are not well constrained but most have errors of about 100 m. There commonly are two locations, one for the sample and one for the vent or main volcano. To facilitate visualization of regional variations, the latitude and longitude for each sample and vent have been converted to distance along the volcanic front (azimuth 120°) and distance back. The origin is an arbitrary point 22 km NW of Telica volcano at the NW end of the volcanic front. The Central American volcanic front is nearly a straight line with a few right steps, so a simple rotation provides an adequate measure of distance along the volcanic front. All distances were calculated in km using a Lambert conical conformal projection which was then rotated 30° clockwise to reflect the overall orientation of the margin.

More accurate latitudes and longitudes are available for those volcanoes with a kml file. These are text files with location data in Google Earth format. The kml files are linked to the RU_CAGeochem page at EarthChem. In the kml files the errors caused by different map projections were minimized by comparing Google Earth images and the field maps. The positions in Google Earth were brought into agreement with the field maps. The new latitudes and longitudes were then copied into RU_CAGeochem. These data currently exist for Telica, Cerro Negro, Irazú, Turrialba and Ilopango. More kml files will be added to the EarthChem link as time permits.

The third metadata group includes physical and tectonic parameters of the major volcanoes and volcanic centres. The volcano heights above sea level and the edifice heights, calculated by subtracting the regional elevation, are the first entries. The sizes of the volcanoes and volcanic centres in km² are next, followed by a crustal thickness estimate based on Bouguer gravity and elevation (Carr, 1984). Tectonic parameters, most notably, "H", depth to the seismic zone, comprise the last several columns. Most come directly from Syracuse and Abers (2006) but the last one, dip poly (used in Figure 1), is an alternative estimate of slab dip derived from their map of isobaths of the seismic zone beneath Central America.

Finally, the structure of the workbook itself includes important metadata. There are 12 tabs because the data include samples from different tectonic settings and different ages. The first tab identifies the database, the second tab describes the column structure of the sheets. The last tab includes references to publications and a list of theses from our group. The next to last tab is a compendium of analytical data obtained on United States Geological Survey (USGS) standards by most of the techniques used to assemble RU_CAGeochem. The most important tabs are the Central American Volcanic Front (CAVF), and behind volcanic front (BVF), the monogenetic volcanism that commonly begins just behind the volcanic front and extends 100 or more km behind it. These primarily monogenetic volcanoes are substantially different from the volcanic front and it is confusing to mix them without marking them with different symbols (e.g. Walker, 1981; Walker et al., 1995, 2003). Finally, the Components tab has useful regional geochemical data on Peruvian metamorphic rocks, Cretaceous intrusives and Tertiary marine sediments from DSDP hole 495.

The other tabs separate samples that are somewhat unusual but nevertheless have intrinsic value. Older rocks (VF Older than 600 ka) from prior instances of the volcanic front contain many samples with ⁴⁰Ar/³⁹Ar dates, mostly from Plank et al. (2002) and Carr et al. (2007). A tab called, Plank et al. (2002); includes ICPS major and trace element data and many new ¹⁰Be/²⁶Be measurements (Kelly, 2003) for the modern volcanic front in Nicaragua and Costa Rica. The tab, REEs Altered, is a cautionary tale concerning the occasional extreme redistribution of REEs in lava varieties that do not outwardly appear severely weathered (Patiño et al., 2003). The tab, Rose_Centam, includes the extensive collection of XRF analyses for Guatemalan volcanics that comprised a substantial portion of CENTAM. Finally, because of its ongoing eruption, there are many studies of Arenal volcano in Costa Rica, creating an overemphasis on this volcano in any regional geochemical comparison. The Arenal_Tephra tab places an extensive tephra database (Bolge et al., 2004, 2006) in a separate table, reserving the lava samples and a few representative tephra samples for the CAVF tab.

6. Future of RU_CAGeochem

The data presented in the current version of RU_CAGeochem extend through the last regional compilations by our group (Carr et al., 2007; Bolge et al., 2009). More recent publications by our group (e.g. Gazel et al., 2009, 2011; Saginor et al., 2011, 2013) have a broader focus, tracing the history of arc volcanism back into the Oligocene and expanding the geographical coverage into Panama. In contrast, RU_CAGeochem is strongly focused on the currently active volcanic front of the Cocos-Caribbean plate margin.

A companion compilation, based on available data from the literature for Central America and the Izu-Bonin-Mariana arc systems is downloadable from Integrated Earth Data Applications (Jordan et al., 2012).

The international databases, such as EarthChem (http://www.earthchem.org/ or specifically, the Geochemistry of Rocks of the Oceans and Continents, GEOROC), provide the geochemical community with superb global coverage. A downside of large international databases can be the loss of metadata that are
specific for small regions but considered vital by authors of the original data. For example, a search of GEOROC for Central America will recover most of the volcanic front data in RU_CAGeochem but will return much more besides, including dredge samples, much older rocks and many sediments. Careful filtering of the GEOROC data recovers the well-established regional variation in Ba/La along the Central American volcanic front but this pattern is not obvious in the raw data and it is not clear that it would be found without knowing it was there and expressly looking for it. One of the strongest motivations of placing RU_CAGeochem separately in EarthChem is that the metadata of sample location, sample type, data quality, age etc. are preserved along with the geochemical data. In this way, the views and or biases of the authors are preserved and can be re-examined easily.

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