growth as well as the poor spatial resolution of traditional isotopic dating techniques. Allanite, a Th and LREE-rich epidote mineral, offers the unique opportunity to couple intra-crystal age distributions obtained via in situ ion microprobe analysis with the range of chemical variations in this compositionally rich mineral and therefore to resolve the timescales of magmatic evolution recorded by mineral zoning. We present the time-composition characteristics of chemical zoning in volcanic allanite (Th and LREE-rich epidote mineral) from compositionally diverse (69-75 wt.% SiO_2) pumice associated with the voluminous (~3000 km^3) Youngest Toba Tuff, Indonesia, erupted at 75 ka. High ThO_2 concentrations (1-2 wt.%) in the Toba allanite allow in situ determination of ages from the magnitude of ^{238}U-^{230}Th disequilibrium in grains less than ~500 ka in age; most ages in the Toba allanite are ≤150 ka with most rim ages identical to that of eruption. Optically recognizable/identifiable zoning in the Toba allanite is on the scale of 10's of microns and is defined by changes in both major and minor elements. Electron probe analyses reveal core-to-rim zoning trends of decreasing LREE, MgO, and La/Nd, and increasing MREE, FeO, and ThO_2, which can be simply ascribed to progressive growth from an evolving melt. However, less-abundant grains display opposite zoning trends and/or contain resorbed and evolved cores, suggesting complex crystal and magma histories. Intracrystal core-to-rim age distributions suggest that the allanite zoning records crystal growth and magmatic evolution involving crystal-melt fractionation over 10's of ky. Furthermore, the coupled time-composition relations between different allanite are disparate such that there is no distinctive concentration of major or minor elements in the crystals at any absolute age. This in turn suggests a complex growth/magmatic history for individual allanite and/or their host melts in this voluminous rhyolite. One consequence of this is that correlations of growth histories between associated allanite grains should be approached with caution.

V32D-1020 1330h POSTER

Calderas of the Central Sector of the Mexican Volcanic Belt

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The central sector of the Mexican Volcanic Belt (MVB) (-99 to 103, Long W) has the largest number of calderas so far identified in this province. The calderas (with their age range in Ma, and distance to the Middle America Trench in km, in parenthesis) are: Amazcala (7-6, 480), Apaseo (7-6, 440), Huichapan (5-4, 420), Agustinos (5-4, 400), Amealco (5-4, 400), Macua (4-3, 410), Muerta (?, 380), Catedral (6-5, 370), Azufres (4.5-0.03, 370 Pradal & Robin, 1994), and Zitácuaro (12-0.5, 320 Capra et al., 1997). Most calderas completed their activity in about 1 Ma, but Azufres and Zitácuaro had longer lives, mostly as post-caldera lava domes and associated pyroclastic flows. Amazcala is rhyolitic, peraluminous-peralkaline, and 10x14 km in diameter. Apaseo is a 11x14 km center that started as andesitic-dacitic and ended rhyolitic and mildly peraluminous; Huichapan started with dacitic ignimbrites and ended with a major rhyolitic ignimbrite; Agustinos is a > 6 km open semi-circle structure that erupted first an andesitic ignimbrite and then a rhyolitic one; Amealco is 10 km in size and erupted a succession of three ignimbrites with mingled glasses with compositions from trachyandesite to rhyolite; Macua is a summit crater structure, 3x5 km, that erupted an unwelded rhyolitic ignimbrite; Muerta is a sector collapse caldera, 4x5 km, associated to lithics-rich ignimbrite eruptions; next to Mexico-City is Catedral, a 9x6 km in diameter caldera with silicic ignimbrites and rim and central lava domes, some of which erupted block-and-ash flows; Azufres has being a matter of debate, but according to Padral and Robin (1994), is a long-lived structure, about 20 km in diameter, with the major caldera eruption at 4.5-3.4 Ma, and repeated dome and pyroclastic flow activity until 26 Ka ago; Zitácuaro (Capra et al., 1997) is another long-lived center, with eruptive cycles at 12 Ma (the caldera-forming event), 5 Ma and 0.5 Ma (mostly domes and associated pyroclastic flows). Most calderas cluster at 4-6 Ma and at 370-420 km from the actual trench. This peak in caldera eruptions coincides with major plate reorganizations offshore SW Mexico, such as the opening of the Gulf of California, an eastward jump of the East Pacific Rise (EPR), and a change from fast to slower spreading rates at the EPR and the Rivera-Pacific rise, which may be related to an increase in explosive volcanism in the central MVB.

V32E MC: Hall D Wednesday 1330h

Plutonic Systems: Felsic to Basic

Presiding: A Schmitt, UCLA

V32E-1021 1330h POSTER

Rb-Sr Isotopic Systematics of Felsic Igneous Rocks, Wichita Mountains, Oklahoma

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Recently determined Rb-Sr isotopic characteristics of twelve of the recognized felsic units of the Cambrian Southern Oklahoma Aulacogen, which crop out in the Wichita Mountains of the southwestern Oklahoma, give some clues to the petrogenesis of these felsic units. 1) Plots of $^{87}Rb/^{86}Sr$ vs. $^{87}Sr/^{86}Sr$ form subsets yielding dates of 516 Ma and 522 Ma, discrepancies of about 10 to 20 Ma from the U-Pb zircon age for the Mount Scott Granite of 534 Ma, probably attributable to a systematic loss of radiogenic ^{87}Sr for these units. 2) The Mount Scott Granite and related units (n=7) including Medicine Park Granite and Saddle Mountain Granite give a probable pseudoisochron of 516±4Ma and an initial $^{87}Sr/^{86}Sr$ of 0.7045±4, indicating derivation from a primitive mantle source with little crustal contamination. 3) A well-regressed line of 522±2 Ma with an initial $^{87}Sr/^{86}Sr$ of 0.7059±7 is shown by the Long Mountain Granite (n=3), one of the finer-grained western granites, and the Fort Sill Section of the Carlton Rhyolite (n=2) in the eastern Wichitas, which indicates that both were possibly derived contemporaneously from a mixed crustal-mantle source. 4) The Lugert Granite of the western Wichitas has variable and relatively high $^{87}Sr/^{86}Sr$ initials at 516 Ma probably indicating heterogeneous crustal sources. Interpretation of these data can be made with the following scenario: The earliest known felsic unit is the Carlton Rhyolite, Fort Sill Section. This must have been generated mostly from crustal melting around large mafic plutons in the mid- to lower crust. Crustal melting around the mafic plutons continued to generate liquids rising to the emplacement position, e.g., Long Mountain Granite. Following this, the host magma for the Mount Scott set of units originated dominantly by fractional crystallization from the mafic plutons. Subsequently, additional mafic magma must have moved into the lower- to mid-crust, at some other stratigraphic level, melting a more heterogeneous mixture of rock types to yield the Lugert Granite. Thus, in this rather narrow rift zone, felsic magmas of varying origin, but similar chemistry, have risen to the same emplacement level.

V32E-1022 1330h POSTER

Trace Elements in Igneous Quartz: a new Petrogenetic Tool for the Study of Granite Pegmatite Genesis

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The trace-element chemistry of quartz is rarely, if ever, considered when evaluating the origin and evolution of silica over-saturated igneous rocks. Analytical obstacles have efficiently prevented in-depth studies of the trace-element chemistry of quartz because the most interesting elements are present at the sub-ppm level and because mineral separation of quartz for traditional solution analysis is a time-consuming process. Also, igneous quartz may contain both fluid and solid inclusions that are difficult to identify during hand-picking and may influence the analytical results significantly. However, in the present study we utilised in situ Laser Ablation of quartz specimens with direct introduction of the ablated material in to a double focusing sector field, ICP-MS instrument, and we developed a method that is fine-tuned for the analysis of trace elements in quartz (Flem et al., Chemical Geology, in press). Among the elements covered by the method we have focussed on substitutional trace-elements replacing Si4+ (e.g. Ti, Ge, Al, Fe and P) or elements that represent charge compensators that are accommodated in lattice vacancies or in structural channels (e.g. Li, B, K, Ca, Be).

Elements analysed at low, medium and high resolutions include Li, B, Be, Al, Mn, Ge, Rb, Sr, Ba, Pb, Th, Mg, P, Ti, Ca, Cr, Fe and K. 29Si or 30Si, were used as internal standards.

In the present study we evaluate the chemical evolution of quartz by comparing with the chemistry of co-existing alkali-feldspar, for which the compositional changes during igneous evolution is well known from the literature.

The study includes 75 strongly zoned gadolinite-type REE-Nb-Ta rich chamber pegmatites from two major Neoproterozoic pegmatite fields in SE-Norway. Analysis of alkali-feldspar for major and accessory elements including the REE shows that the pegmatites were formed from progressively more evolved liquids through extreme fractionation of primitive granitic melts.

The total concentration of trace elements in quartz is 100 to 250 ppm with Al, P, Li, Ti, Ge and Fe, in that order, being most abundant. Distributions of trace elements in quartz are well correlated with major and trace elements in alkali-feldspar that are used to monitor the chemical evolution of the granite pegmatite liquids. For example, Al, Ti and Ge are positively correlated with Ca and Sr in alkali-feldspar. Accordingly, the trace element distribution in quartz develops a progressively more evolved signature as igneous differentiation of the parental melts proceeds. Although the pegmatite fields apparently are closely related both in terms of space, time and chemistry, the distribution patterns of trace elements in quartz are markedly different thus suggesting that granite pegmatites in the two fields were derived from distinctively different sources. This conclusion is confirmed by the REE-chemistry of alkali-feldspar and by the REE-mineral assemblages characterising the pegmatite fields.

V32E-1023 1330h POSTER

Limitations on Mid-crustal Assimilation in the Sierra Nevada Batholith (SNB), California

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The extent to which pre-existing continental crustal components have been introduced into granitic magmas of the SNB as melted sediments within source and/or ascent domains has been the focus of much attention. In order to test the potential importance of this process at relatively deep ascent levels (3-5 kb) we have performed a detailed study of one of the best developed migmatite complexes observed throughout the metasedimentary framework of the SNB, and in the immediately adjacent 100Ma Goat Ranch granodioritic intrusion (GRg), which drove partial melting in a 50 ~500 m wide zone in adjacent psammitic-pelitic rocks. Isotopic analyses of Nd and Sr, and major and trace elemental abundance were measured on non-migmatitic distal wallrocks (sillimanite grade), leucosomes from the migmatites; and on traverses into the GRg away from contacts with the migmatites. We also analyzed a suite of mafic enclaves in the GRg which yielded bulk compositions of andesite and which have mineralogically equilibrated with the host GRg. Sr(i=100Ma) of GRg range from 0.7061 to 0.7071, and υ_{Nd}(i) from -1.1 to -6.5, while mafic enclaves yield a similar range. Leucosomes have Sr(i) from 0.7125 to 0.7247, and υ_{Nd}(i) from -6.0 to -11.3 while nonmigmatitic metapelites yield a similar range Contamination of GRg, as seen by large shifts in Sr(i) and υ_{Nd}(i) is restricied to immediate proxity to migmatitic wallrocks. Isotopic heterogeneity of the GRg is not related to assimilation at or near the level of exposure, a similar conclusion reached for 100 Ma (ca. 8kb) SNB rocks located further south in an oblique crustal section (Pickett and Saleeby ,1994). Isotopic variation patterns in 10-20 kb SNB lower crustal residue assemblages carried as xenoliths in Neogene volcanic rocks lie along the same trend as the GRg data (Ducea and Saleeby, 1998), and suggest that the GRg heterogeneity is inherited from such a source. Leucosomes in the migmatite complex appear to have crystallized nearly in place after segregation. This as well as the limitation in contamination of the GRg appears to have been energy limited. Mafic enclaves in the GRg strongly resemble remnants of disrupted commingled mafic dikes observed elsewhere in the southern SNB. Elemental chemistry shows that they are not residues from melted metapelite. There was possible isotopic exchanges (particularly Sr) between the enclaves and GRg.

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V32E-1024 1330h POSTER

Statistical Distribution of Leucocratic Melts in the Swakane Terrane, North Cascades Crystalline Core, WA: Implications for Melt Transport and Collection in Deep Crust

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It has been proposed that melt collection and transport in the crust is controlled by low stress pathways influenced by anisotropy, including foliation or bedding, and/or by active deformation represented by local or regional folding, shearing, and boudinage. We examine this idea in the Swakane quartz biotite gneiss (SBG), Cascades core, Washington. The SBG is the deepest exposed section in this Cretaceous to Paleogene magmatic arc. Published pressures of 10-12 kbar in the SBG, indicate that > 40 km of exhumation have occurred since peak metamorphism (Valley et al., 2000). The SBG displays a strong, pervasive foliation, both regional and local folding, and pervasive shearing. A conjugate set of ∼68 Ma leucocratic intrusions in the SBG are composed of quartz + plagioclase + muscovite + garnet + biotite. They have large length to width aspect ratios, in many cases are less than 15 cm thick, and because of their composition and shapes are interpreted to be locally derived and locally transported melts of the SBG. During melt transport and collection, the entire unit was undergoing exhumation by SW-NE contraction, and arc-oblique, top-to-the-north shear.

Preliminary observations indicate that prior to deformation most of the veins in the Columbia River area formed a conjugate set with the dominant set of veins parallel to foliation. However, numerous examples exist where veins maintain a consistent orientation independent of all structures. The acute intersection of these veins indicates that $\sigma 1$ is sub-horizontal, and approximately SW-NE, and $\sigma 3$ is vertical. Outcrops in Tamarack Creek, which represent a slightly shallower part of the SBG, show a similar pattern of conjugate veins, but here neither set of veins is parallel to foliation. This stress field is consistent with the regional stress field for SW-NE contraction in the NCCC. In both locations, veins injected at an angle to foliation are more deformed suggesting that deformation was still active as intrusion continued. We suggest that the orientation of leucocratic veins in the Swakane was a result of the regional stress field, and relatively independent of all host rock structures.

V32E-1025 1330h POSTER

Intrusive emplacement and thermal history of the Geysers Plutonic Complex, northern California: New insights from in-situ U-Pb zircon dating

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The Geysers Plutonic Complex (GPC) is a unique example of a Quaternary intrusion that is exposed at shallow subsurface levels (>0.7 km depth). It spatially overlaps with a major surface heat-flow anomaly that is associated with one of the world's largest geothermal fields, known as The Geysers. Based on drill hole penetration, the GPC appears as an elongated northwest-trending keel shaped body which has an areal extent of 50 km^2. It has been petrographically subdivided into microgranite porphyry, granite and granodiorite and compositional similarities of these subunits linked them to the extrusive rhyolites and dacites from the Cobb Mountain volcanic field (CMVF) that overly the GPC at its eastern margin, but little is known about the relative timing of the intrusive and related volcanic activities. Age determination of the GPC requires in-situ techniques due to xenocrystic contamination of drill cuttings that are generally the only available materials from the GPC. Meaningful ages reported in the literature are limited to four samples from the GPC granite unit that range from 1.13 to 1.25 Ma ($^{238}U/^{206}Pb$ ages uncorrected for initial ^{230}Th deficit). Here we present U-Pb zircon ages for an extended sample set that covers all subunits of the GPC and the CMVF. These ages provide new constraints on the onset and duration of intrusive emplacement of and eruptive tapping from a shallow magma body.

Apparent $^{238}U/^{206}Pb$ ages (1.52 - 1.74 Ma, 1σ uncertainty typically <5 % relative) for five samples of microgranite porphyry including a microgranitic dike rock exceed the ages determined for the granite and granodiorite units (1.13 - 1.25 Ma, 14 samples total). One well at the eastern margin of the GPC penetrated 0.8 km of previously unidentified biotite-orthopyroxene-hornblende granite that yielded slightly younger $^{238}U/^{206}Pb$ ages between 1.05 and 1.08 Ma (three samples). U-Pb zircon ages from the CMVF (Alder Creek rhyolite: 1.24 ± 0.04 Ma; Cobb Mountain rhyodacite: 1.24 ± 0.04 Ma; Cobb Valley rhyodacite: 1.20 ± 0.05 Ma) closely overlap with the age range of the granite and the granodiorite samples. Initial ^{230}Th deficit in zircon results in radiogenic ^{206}Pb contents that are on average by 5-10 % too low, and therefore an average +0.10 m.y. age correction is required. After applying this correction, we obtain an average zircon crystallization age for the CMVF that is about 0.20 m.y. older than the eruption ages implied by Ar-Ar sanidine ages (1.15 ± 0.01 to 1.01 ± 0.06 Ma). The eruption ages, however, are similar to the corrected zircon crystallization ages of the youngest GPC unit, the biotite-orthopyroxene-hornblende granite.

The data indicate a complex intrusive history of the GPC and a time span of at least 0.8 m.y. for its formation. Volcanic activity is temporally and spatially linked to the last intrusive phase but the erupted magmas appear to consist of remobilized older materials of previous intrusions. Intrusive activity within the main body of the GPC ceased at ∼1.0 Ma which suggests that the GPC at its presently known extent is unlikely to be the heat source for the present-day heat-flow anomaly at the Geysers steam field.

V32E-1026 1330h POSTER

How Useful are K-feldspars in Ar/Ar Thermochronology? The Case of the Catalan Coastal Batholith (NE Spain)

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The ubiquity of K-feldspars and their simple chemical formulae has attracted the attention of geochronologists since the development of the K/Ar method in the fifties. Nevertheless, it was rapidly understood that K-feldspars do not retain all radiogenic argon in many cases. This fact discouraged the detailed study of this mineral and only in the nineties the important growth of the Ar/Ar method and the possibility of carrying out diffusion experiments have been used to decipher thermal histories. How, if any, credibility can be assigned to these thermal reconstructions has been a matter of discussion during the last years. The main trouble is the extraordinarily complex structure of real K-feldspars, in fact, one of the most intricate in nature. Although, in principle, these structures can give themselves the clue for the resolution of the problem, there are an excessive number of unknowns, being one of the most fundamental the age of their formation.

We present here a detailed study of several K-feldspars from the late-Hercynian calc-alkaline Catalan Coastal Batholith (NE Spain). Optical microscopy, electron microprobe, X-ray diffraction, and stable and radiogenic isotope studies have been carried out on them. A good correlation between obliquity deduced by XRD and Ar/Ar total fusion ages gives evidence of an age-microstructure correlation. We infer that most microtextural changes occurred during cooling of the batholith, but a late disturbing Mesozoic (?) hydrothermal event of weak intensity and with only minor fluid circulation must have occurred, which enhanced the structural changes already present during the deuteric stage. This event provoked significant argon loss in the most structurally complex K-feldspars and is recorded in the hydrogen, but not oxygen, isotope data. No clear information can be deduced from Ar/Ar spectra, so thermochronology modelling of these complex K-feldspars is not possible, and can not give any geological response due to the lack of cognisance of the true age of microstructure development. We conclude that K-feldspar modelling can a priori makes sense only in a small set of cases without important post-crystallisation changes, i.e. simple geological histories. Nevertheless, the presence of featureless orthoclase in epizonal plutons seems to be a good indicator of an undisturbed system, so the determination of the structural state of these K-feldspars by XRD and microscopic study, appears to be a good and inexpensive starting point for doing geochronological research in these type of rocks.

V32E-1027 1330h POSTER

U-Pb geochronology of Permian - Jurassic plutonism in the Ogcheon fold belt and the Ryeongnam massif, Korea

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The Ogcheon fold belt and the Ryeongnam massif are made-up of Precambrian igneous and sedimentary rocks that have been metamorphosed, tectonically deformed, and extensively intruded by mafic to felsic plutonic rocks of Permian to Jurassic age. The Ogcheon fold belt is a folded and thrusted metasedimentary terrain that separates the Ryeongnam massif from the Gyeonggi massif. The Ryeongnam massif is predominantly a granitic terrain, while the Ogcheon fold belt consists mainly of Early Paleozoic to Early Mesozoic metasedimentary rocks, which are characterized by high pressure and low temperature metamorphism. A total of 20 U-Pb ages indicate that the plutonism in the Ogcheon fold belt is coeval with that in the Ryeongnam massif, it is Permian to Jurassic, between 252 and 173 Ma. These ages are lower concordia intercepts; the upper concordia intercepts indicate derivation from a Precambrian protolith. This plutonism may be a continuum of igneous activity or it may be episodic. We tentatively suggest that it is episodic. Foliated plutons were emplaced in three episodes at 253, 205-230 and 180-200 Ma followed by non-foliated, post tectonic, plutonism at 170-180 Ma. The plutonic and tectonic activity in Korea can be related to that in China. China has experienced extensive plutonic and tectonic activity in Permian, Triassic, Jurassic and Cretaceous, between 253 and 90 Ma. Both, in Korea and in China this Permian-Jurassic plutonic and tectonic activity may be the result of the continental collision of the South China Block (Yangtze plate) with the North China Block (Sino-Korean plate).

V32E-1028 1330h POSTER

Nd and Pb isotope geochemistry for Neoarchean alkaline intrusions in the western Superior Province, Canada

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Small volume post-tectonic alkaline intrusions of Neoarchean age are abundant in the western Superior Province. This study concentrates on the Quetico alkaline province, which consists of 15 bodies intruded between 2680 and 2690 Ma and comprises both mafic and felsic intrusions. The rock types include clinopyroxenites, hornblendites, monzodiorites, syenites and silico-carbonatites. The country rocks are slightly older (2695 Ma) (Davis and Corfu, 1995, Precambrian 95 Program and abstracts, p. 34) meta-turbidites, which are geochemically similar to the felsic intrusions with respect to most major and trace element concentrations. Compared to primitive mantle values the samples are enriched in LILE, in particular Ba and Sr, and variously depleted in HFSE relative to neighboring REE. They have strongly fractionated REE patterns with $(La/Yb)_N$ ratios between 3 and 64.

Nd isotope ratios of the alkaline intrusions display significant variation both within single intrusions and on a regional scale. $\epsilon Nd_{(2680)}$ ranges from +4.7

to -0.5, suggesting that the intrusions do not represent partial melts from a homogenous depleted upper mantle, and indicate little involvement of significantly older crust. In contrast Pb isotope ratios of leached K-feldspar from the felsic plutons are indicative of some contamination with the surrounding metasediments: $^{206}Pb/^{204}Pb$ = 13.619 - 15.273; $^{207}Pb/^{204}Pb$ = 14.624 - 14.984; $^{208}Pb/^{204}Pb$ = 33.303 - 33.938. There is positive correlation between $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ and a less well defined positive correlation between $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. $^{207}Pb/^{204}Pb$ further correlates negatively with La/Nb and positively with SiO_2.

Within the Quetico alkaline province REE/HFSE ratios are consistent with a model involving partial melting of a metasomatized mantle wedge. The intrusions are post-tectonic, indicating that igneous activity was not contemporaneous with subduction, but occurred after subduction ceased. Most lithologies are carbonate bearing suggesting a prominent role of CO_2 rich fluids in in the mantle wedge prior to melting, and the LILE and LREE budget of the Quetico alkaline province appears to be largely controlled by variable fluid flux into the subarc mantle.

V32E-1029 1330h POSTER

Intra-crustal Seismicity Controled by Caldera-forming Plutons on Cooling in NE Honshu Arc, Japan

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The NE Honshu arc is a mature double volcanic arc with the most completely studied Cenozoic section. It can be divided into three prominent periods of volcanic activity: continental margin, back-arc basin, and island arc volcanic period. The island-arc stage can be divided into four phases: submarine volcanism (13-8 Ma), late Miocene caldera-forming phase (8-5 Ma), Pliocene caldera-forming phase (5-1.7 Ma) and compressional volcanic arc (1.7-0 Ma). The thermal structures seen in the upper crust of the present NE Honshu arc are closely related to the distribution of the Late Cenozoic collapse calderas in the central mountainous range parallel with the volcanic front (Yoshida et al., 2000). The formation of the felsic calderas suggests the emplacements of shallow, large-scale magma reservoirs within the crust. Felsic plutons on cooling from the magma reservoirs, probably exist now at comparatively shallow depths under the calderas in the NE Honshu arc. The analysis of the thermal history of the NE Honshu arc by the petrological studies of volcanic rocks and the studies of organic maturation (Ban et al., 1992; Yamaji, 1994; Yoshida et al., 1995) show the paleogeothermal gradient in the Miocene was greater than at present, and subsurface temperature appears to have fallen through the Pliocene to Quaternary in the fore-arc to axial region of the NE Honshu arc. Westward retreat of the volcanic front (Ohguchi et al., 1989) is also in accord with the regional cooling in the NE Honshu arc. Intensive water discharge will occur in the water saturated felsic magmas during its cooling (Kimura et al., 1999) and hydrothermal systems will develop around the plutons. Magmas in super-solidus and even in sub-solidus states on cooling can be well detected as low-Vp bodies in both the lower and upper crusts, and the discharged fluid infilling cracks can act as seismic reflectors around the cooling plutons. The locations of crustal low-velocity areas, high seismicity areas, focal mechanisms of inland earthquakes and S-wave reflectors (bright spots) together with the estimated thermal structures are closely related with the distributions of the Late Cenozoic calderas of piston-cylinder type (Umino et al., 1998). Unexposed plutonic bodies on cooling must be existing now at middle crustal depths under each Late Cenozoic caldera, and probably they are observed as low-velocity bodies with many S wave reflectors. The solidus of water-saturated granitic magma is crossed with an estimated geotherm of the NE Honshu arc at around 20km depth. This means that wet granitic magmas and related plutons are in super-solidus at middle crust during they hold water and will live for a long period as low-velocity bodies with surrounding S-wave reflectors of sheeted veins. The distribution pattern of S-wave reflectors around the Onikobe caldera swarm is systematically changes with depth. At the shallowest level, the dip angle of reflectors is nearly vertical and it becomes to horizontal at deeper depths. The distribution of S-wave reflectors also changes with depth from northeastern to eastern side of calderas. These changes of the mode of occurrence of S-wave reflectors could correlate with the temporal change of regional stress regime, and with the cooling history of deep-seated plutons. The change of regional stress axis from NE-SW to EW direction occurred at about 1Ma in the NE Honshu arc (Umeda et al., 1999) and resulted crustal shortening stopped the caldera formation of piston-cylinder type. This event is the most attributable to the change in the distribution pattern of S-wave reflectors with depth together with the change in the mode of volcanic activity.

V32E-1030 1330h POSTER

New Constraints on the Origin and Emplacement of Granitoid Magmas in the Waldoboro Pluton Complex, Maine

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The Waldoboro Pluton Complex (WPC) is dominated by two-mica granite and by granodiorite that intruded the Merrimack-Harpswell and St. Croix terranes of Coastal Maine in the late Devonian (ca. 368 Ma). The country rock in the vicinity of the WPC contains numerous layer-parallel granitic veins and contacts between the WPC and the country rock are frequently gradational. These and other observations have been interpreted to indicate in-situ granite formation by melting of metamorphosed (amphibolite facies) wackes of the Bucksport Formation. However, new modal and mineral chemical data make this interpretation unlikely. In particular, hydrous mineral (biotite and amphibole) abundances in the Bucksport Formation are too low to provide the water necessary to generate abundant granite melt at the P-T conditions (0.5 GPa, 670-740 ^{O}C) inferred for crystallization of the WPC. Also, Bucksport lithologies are characterized by An-rich plagioclase (29-91 mol%), Ca-rich garnet (0.9-1 afu) and (mostly) Ti-poor biotite (0.1-0.22 afu) and appear to be inappropriate source rocks for peraluminous granitoids. Detailed studies of samples from individual localities reveal large compositional differences between feldspar (>29 versus <10 mol% An), garnet (>25 versus <1 mol% grossular; <15 versus >25 mol% spessartine) and biotite (Mg#<0.12 versus 0.35; Ti>0.36 versus 0.22 afu) in host Bucksport-like country rock and granitic veins. This strongly suggests that the granitic veins represent injected melts rather than migmatite leucosomes and that most garnets in the granitoids are magmatic rather than restitic. Some garnets with Ca-rich cores and Ca-poor rims in the granitoids are probably xenocrysts derived from the country rock and indicate mixing between country rock and magma. Field observations indicate that intrusion of the WPC locally induced melting in pelitic lithologies (eg. those of the Penobscot Formation), and this interpretation is supported by mineral chemical data (feldspars, garnets and biotites have similar compositions in melanosomes and leucosomes). However, pelites are relatively rare in the vicinity of the WPC so that in-situ formation from such lithologies is highly improbable. It is concluded that the granitoid magmas of the WPC formed by anatexis of meta-graywackes and/or meta-pelites at pressures greater than 0.5 GPa. Comparison of whole-rock chemical analyses with experimental data for the system Q-Ab-Or suggests emplacement and crystallization of the WPC under water-saturated conditions at about 0.5 GPa.

V32E-1031 1330h POSTER

Windows into Basement Structure Exposed in the Footwall of the Wasatch Fault: The Santaquin and Farmington Canyon Complexes

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The Santaquin complex [SC] and Farmington Canyon complex [FCC] are two of very few basement rock exposures in the footwall of Wasatch Fault, Utah. The SC is dominated by igneous and metamorphic lithologies. Mineral ages show that SC rocks underwent amphibolite-facies metamorphism prior to 1650 Ma. Unstrained mafic syenite has as a 1673±23 Ma U-Pb age [zircon] and a 1623±5 Ma $^{40}Ar/^{39}Ar$ plateau age [hornblende]. Sr- [errorchron] and Nd-isotope data [T_{dm}s] are also consistent with crust formation at ~ 1650 Ma. Whole-rock Pb-isotope data are discordant, however, and give a $^{207}Pb/^{206}Pb$ age of ~1400 Ma.

Mafic to intermediate rocks of the SC have high LILE/HFSE ratios, whereas granitic rocks have low Nb and moderate Y, indicative of derivation in an arc. $^{87}Sr/^{86}Sr_i$ and $^{143}Nd/^{144}Nd_i$ are also consistent with arc magmatism. Thus, the SC represents an arc terrane accreted to the Archean craton, requiring a suture [Cheyenne belt?] to lie northward.

North of the SC, the FCC is considered to be Archean basement based on published T_{dm}s and discordant U-Pb zircon ages, albeit strongly overprinted at 1800 Ma (Hedge et al., 1983). However, Nd T_{dm}s and zircons can be inherited from sediment. Published U-Pb ages on monazite (Barnett et al., 1993) are 1650 to 1700 Ma. Although monazite, once formed, is as retentive as zircon, it shows no sign of inheritance. Instead, monazite is believed to form during prograde metamorphism of sedimentary phosphate. Thus, we propose that the FCC was cratonized from Archean-derived sediments at 1800 Ma. Thus, new data from SC and reinterpretation of the FCC suggest that a serious re-evaluation of basement architecture in Utah is warranted. Indeed, the Cheyenne belt may lie to the north and east of the FCC.

V32E-1032 1330h POSTER

Oxygen Isotopes and the Cooling History of the Mount Barcroft Area, Central White Mountains, Easternmost California

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The White-Inyo Range + Owens Valley marks the western limit of the Basin and Range province, directly east of the Sierra Nevada. At Mount Barcroft, mid-Mesozoic, alkaline, bimodal White Mountain Peak metavolcanic + metaclastic rocks on the N are separated from Lower Cambrian siliciclastic + carbonate metasedimentary strata on the S by the NE-trending Middle Jurassic Barcroft mafic granodioritic pluton. It consists of mineralogically/chemically intergradational gabbro/diorite, granodiorite, metadiorite, and alaskite. Eastward, the section is intruded by the Late Cretaceous, ternary-minimum McAfee Creek Granite. Ignoring altered dikes, bulk-rock analyses of plutonic rocks indicate that metaluminous, I-type rocks of the Barcroft comagmatic suite possess an av(12) d18O value of 7.5. Slightly peraluminous, apparently S-type granitic rocks sensu stricto of the McAfee Creek series have an av(8) d18O value of 8.6. Evidence is lacking for large-scale bulk-rock interaction with near-surface waters, suggesting intermediate crustal depths of intrusion and cooling for these plutons.

Coexisting Barcroft minerals exhibit consistent oxygen isotopic partitioning from high to low d18O in the sequence quartz > plagioclase > K-feldspar >> amphibole = biotite. Wall-rock quartz and biotite are richer in 18O than analogous phases in the plutonic rocks, and show slightly greater fractionations than igneous counterparts. Along its borders, late-stage exchange with heated aqueous fluids, derived from recrystallized wall rocks due to emplacement of the Middle Jurassic magma, increased 18O/16O ratios of dikes, and some Barcroft igneous plagioclase and subsolidus tremolite-actinolite. Oxygen isotope geothermometry for Barcroft quartz-amphibole and quartz-biotite pairs yields broadly similar temperatures; the combined average of 13 pairs is 519°C. A single quartz-biotite pair analyzed from a Lower Cambrian quartzite within the inner metamorphic aureole of the Barcroft pluton yields a temperature of 511°C, in agreement with values based on wall-rock metamorphic parageneses. Barcroft quartz, feldspars, biotite, and clinoamphiboles were subjected to exchange with deuteric fluid, and re-equilibrated under subsolidus conditions. Quartz-plagioclase pairs from two Barcroft granodiorites possess similar temperatures of 519 and 515°C, so also re-equilibrated at subsolidus temperatures. Areal distributions for quartz-plagioclase, quartz-clinoamphibole, and quartz-biotite pairs reveal that annealing temperatures are lowest in axial portions of the Barcroft granodioritic pluton. Late Cretaceous emplacement of the McAfee Creek Granite had little effect on d18O values of Barcroft minerals and bulk rocks.

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V32E-1033 1330h POSTER

The Assembly of Eastern North America: Using Garnet Zoning to Decipher the Potomac Terrane

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The Sykesville Formation, the focus of this study, is in the easternmost Potomac Terrain between Roosevelt Island and Chain Bridge in the Potomac River Gorge on the Virginia side. The Potomac is one of many as yet poorly understood terranes speculatively added to the late Precambrian margin of North America. The remarkably voluminous Sykesville formation extends 125 km and is typically at least 3 km thick. Hopson (1964) recognized it as a gigantic slump deposit that grades westward into the turbidites of the Wissahickon Formation. The work of Hopson has been expanded upon in the many publications of A. A. Drake, Jr. with additional mapping in northern Virginia. The age of the Sykesville protolith is probably over 500 ma and was obducted on to the North American continent probably over 400 million years ago by collision with a deep-sea trench marginal to a mountainous continent or microcontinent. The source area for the protolith in our study area is overwhelmingly continental. Quartz veins and what appear to be metaorthoquartzite bed are common in the Sykesville. The presumed metaorthoquartzite beds was examined by cathodoluminescence. With this analysis, we discovered relict sand grains preserved in a quartz sample. This presents an enigma: the presence of a pure, mature quartz sediment interbedded in an immature feldspathic sandy slump deposit. Were there two quite different source areas feeding into the protolith? We examined garnets using electron microprobe analysis to examine the P-T history of the Sykesville. The garnets show simple zoning patterns, most clearly, as usual, in MnO. Compositional profiles suggest a single episode of metamorphism followed by retrogression, presumably during uplift and erosion after obduction. The age interval of this metamorphism is uncertain but was latest Precambrian or early Cambrian (Penobscot Orogeny). Future analysis of the chemical composition of the garnets will tell us more about the pressures and temperatures that the garnets reached during metamorphism attendant to obduction of the Potomac Terrane to North America. We thank Amelia Logan, Jim Rougvie and Sorena Sorensen of the Smithsonian for their assistance with this project.

V32E-1034 1330h POSTER

Formation of the Kodiak Batholith: a Consequence of Spreading Ridge Subduction

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Subduction of a migrating oceanic spreading center along the southern Alaska margin is the accepted interpretation for the origin of near-trench intrusives in the accretionary complex rimming southern Alaska. The largest of the near trench intrusions is the Kodiak Batholith (58 Ma) which has an aspect ratio of $>$ 20:1, and an areal extent of almost 800 km^2. The main body of the batholith is located 30-40 km from the paleotrench position at 50-60 Ma, and satellite intrusions to the SE may be as close as 1-5 km from the paleotrench. This is far too proximal to the trench for 'normal' arc magmatism.

The strike-perpendicular compositional changes of magmatic intrusions found on Kodiak Island is what would be expected if an actively spreading mid-ocean ridge segment was subducted into an accretionary prism. Close to the paleotrench, basalt dikes and pillows are present, further away, they are not. Paleocene foraminifera have been reported in limestones asociated with the basalts. With increasing distance perpendicular to the paleotrench, the following sequence of intrusions is encountered: small bodies of biotite bearing plagioclase porphyry, coarse grained plagioclase hornblende gabbro, biotite rich granites and finally, the main elongate batholith, which is composed of plag, bio, qtz and k-spar granodiorites. The main batholith appears to have been intruded as a single pulse of magma. This distribution of rock types and compositions is consistent with less, closer to the trench, to more, farther from the trench, interaction of the mafic magmas with the overlying accretionary wedge. Previous workers have found a similar pattern of magmatism on the SW side of the Island, whereas our work focused more of the central and NE portions of Kodiak.

Brittle processes are primarily responsible for the intrusion of the small granitic bodies near the paleotrench. These bodies have relatively sharp contacts and are locally comprised of up to 20-30 % host rock xenoliths. This indicates that stoping is an important intrusion mechanism. This contrasts with the main batholith, in which both ductile and brittle processes are at work. Larger stoped blocks are present, but there is also a ductile aureole in which isoclinal folds and highly strained rocks are present. Ductile deformtion, as well as large (5-10 m scale) host rock blocks, are concentrated on the NW side of the batholith. Ductile processes were also at work along the SE side of the pluton, but to a much smaller degree. The SE side of the batholith is almost entirely berefit of host rock xenoliths of any size. All of the intrusive bodies contain a weak magmatic foliation parallel to and continous with cleavages found in the adjacent host rocks. The relative importance of brittle vs. ductile processes in the central batholith has not yet been determined.

To explain the above observations the following scenario is proposed. Initially, mafic magmas from the spreading ridge intrude into the accretionary prism. The extreme temperature differential ($>$ 1000° C) between these magmas and the accretionary prism induces thermal shattering (e.g. numerous host rock xenoliths) and melting. The melt mingles with the intruding magmas and eventually forms small hypabyssal granitic bodies. Deeper within the accretionary prism, host rock assimilation continues until the melt body attains a positive buoyancy. At this point the granitic magmas intrude upward via a combination of brittle and ductile processes, leading to the creation of the large Kodiak Batholith.

V32E-1035 1330h POSTER

Textural Evidence for Compaction in the Lower Zone of the Bushveld Complex, Republic of South Africa

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A fundamental question in modern studies of magma chambers in general, and layered intrusions in particular, is how they fractionate. Compaction in the mush zone of a crystallizing chamber is gaining favor as a model for fractionation whereby evolved interstitial liquid expelled from the compacting crystal pile is returned to the magma chamber. In this study, we undertake detailed textural analysis of rocks in the Lower and Lower Critical zones of the Bushveld Complex to quantify features that can be attributed to compaction. Ongoing work links textural results with geochemical data, further establishing the role of compaction as a fractionation mechanism in the intrusion.

One textural indicator for compaction is foliation, which is determined by the alignment factor (AF) for oriented samples. In our study, AF decreases with stratigraphic height and foliation is best developed in the pyroxene-rich harzburgite of the Lower Zone. This result is expected: compaction in a mush zone is best developed in single-crystal systems. At the Lower Zone-Critical Zone transition, plagioclase content increases, decreasing bulk density and thus, the systems ability to absorb pure shear through compaction. Furthermore, there is a positive correlation between the quality of the foliation and mineral aspect ratio, a result consistent with compaction: selective grain resorption of unfavorably oriented grains and uneven crystal growth caused by uniaxial stress of compaction can result in grains with high aspect ratios.

We confirm that recrystallization was important in the Lower Zone of the Bushveld Complex by examining crystal size distributions (CSDs). Plots of population density versus crystal size show a log-linear trend overturned at smaller grain sizes, suggesting that larger grains grow at the expense of small ones in the crystallizing pile. Furthermore, Bushveld CSDs have a shape consistent with those modeled for communicating neighbor growth kinetics, wherein diffusion length scale is dependant on distances between neighboring particles.

Textural data are combined with preliminary whole-rock trace element data support compaction in the mush zone. For example, the incompatible element P has low concentrations at high AFs compared with at low AFs, indicating that compaction was important in the redistribution of trace elements. Thus, in situ processes may explain the geochemical and textural features observed in the Bushveld Complex.

V32E-1036 1330h POSTER

Magma Chamber Processes in the Bushveld Complex: Sr Isotopes Constrain Recharge and Mixing at the Pyroxenite Marker

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The 2.06 Ga Bushveld Complex (BC) in South Africa is a 7 to 8 km thick layered succession of ultramafic to mafic rocks that crystallized from a series of major magma recharge and mixing events which are represented in the cumulate succession as the Lower, Critical, Main and Upper Zones. The initiation of the Upper Zone, which is the last and largest of these events formed a prominent orthopyroxenite layer, the Pyroxenite Marker (PM), as a consequence of mixing the resident and recharging magmas. The PM or its stratigraphic position, can be traced all around the complex for several hundred km, and is inferred to have had an areal extent of over 65.000 km2. Initial 87Sr/86Sr data (R0) show that the Main Zone cumulates below the PM have ratios close to 0.7085 whereas the 2 km thick Upper Zone cumulates above PM are constant at 0.7073 and crystallized from a well-blended magma (Kruger et al., 1987, EPSL 84, 51-58; Cawthorn et al., 1991, J. Pet. 32, 739-763). The mixing proportion between evolved residual Main Zone magma and intruding magma (R0 of 0.7063) has been estimated as 1:1 or 2:3.

To further investigate the physical details of magma emplacement and mixing at PM we have analysed Sr isotopes in plagioclase separates from 43 samples taken in 3 vertical profiles across 1.2 to 2.4 km of stratigraphy in the Eastern limb of the BC. The lateral distance between these profiles exceeds 100 km from Thornhill in the north, through Roossenekal to Stoffberg close to the southern margin of the complex in the south. In the thinned mafic sequence at Stoffberg, the PM is absent and a more than 10 km long country rock xenolith occurs at the lateral continuation of the marker. Our data confirm that rocks well below and above the PM have R0s of c. 0.7085 and 0.7073 respectively. Across PM itself, however, the R0s vary considerably (0.7063 to 0.7085) and thus provide a detailed record of the emplacement and mixing processes. Immediately above the PM, the R0s zig-zag between 0.7063 and 0.7080 over 400 meters of section at Thornhill and a similar pattern is seen at Stoffberg (0.7067-0.7080 over 200 m), whereas at Roossenekal samples above the PM are all close to 0.7073. In contrast, R0s remain close to typical Main Zone (0.7085) up to 100 meters below the PM at Stoffberg, and only a few metres below PM in the two other profiles. In a gross sense, R0s correlate inversely with mg number of orthopyroxene and anorthite content of plagioclase reflecting mixing between the evolved resident and new more primitive magmas.

These new data demonstrate the cumulates above PM at Roossenekal formed from a well-blended magma, similar to inference from the Western limb. In contrast, at Thornhill and Stoffberg thick cumulate sections above PM seemingly crystallized from magma isotopically ranging from recharged to resident end member. In the case of the Stoffberg section this incomplete blending may relate to its position close to the margin of the intrusion. We speculate that the Stoffberg section formed in a position that experienced lateral magma chamber expansion. In this model the huge country rock xenolith is considered to represent a sliver of the former roof located at the point of Upper Zone magma recharge.

V32E-1037 1330h POSTER

Ferric/Ferrous Iron in Plagioclase of the Skaergaard Intrusion

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The oxidation state of magma bears on the liquid line of descent and the crystallization products of magmatic differentiation. For example, the differentiation of basalt towards either silica enrichment (rhyolite) or iron enrichment (ferrobasalt) hinges on the amount and composition of FeTi oxides crystallizing, that in turn hinges on magma composition and the redox state of iron. To evaluate the redox state of iron during crystallization of the Skaergaard intrusion we have carried out synchrotron micro beam Fe-XANES (X-ray Absorption Near-Edge Structure) analyses and determined the proportion of ferric iron to total iron (Fe3+/Fe) in plagioclase of the Layered Series. The advantage of using iron in plagioclase over FeTi oxides is that iron is a trace element in plagioclase and that plagioclase is the last phase affected by subsolidus equilibration. In cumulus plagioclase cores Fe3+/Fe range from 74 to 15 (based on calibration against oxides) and correlate positively with the anorthite content. The highest Fe3+/Fe (74 to 47) are in the early fractionation products formed prior to the onset of magnetite crystallization, that is in Lower Zone a and b. In the middle portion of the fractionation sequence above the appearance of FeTi oxides, that is from Lower Zone c through to Upper Zone b, Fe3+/Fe displays large within sample variation and measured values in this portion of the stratigraphy range between 62 and 34 without showing a systematic stratigraphic trend. Finally, in the extremely iron-rich cumulates with fayalitic olivine and sodic plagioclase of Upper Zone c, Fe3+/Fe ranges from 26 to 15.

These Fe-XANES results strongly indicate the Skaergaard magma was relatively oxidised prior to magnetite crystallization but thereafter became more reduced with fractionation. This result corroborates to inference from QUILF equilibrium. Hence the Skaergaard magma chamber must have been closed to oxygen exchange in order to reduce ferric iron in the magma in consequence of magnetite crystallization. While Fe3+/Fe decreases with fractionation, the total amount of FeO in the plagioclase cores (0.24 to 0.46 weight percent) increases with fractionation after magnetite-in. This cannot be explained by crystal chemistry or changing partitioning coefficients. We therefore conclude that the iron content of the magma increased with fractionation even after magnetite-in, and that ferrous iron dominated this iron-rich ferrobasaltic end product.

V32E-1038 1330h POSTER

Deeply Eroded Massif Anorthosite and Nepheline Syenite of the Chimakurti-Uppalapadu Plutons, Peninsular India: Cospatial but not Comagmatic

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Massif anorthosites are generally thought to be ultimately of mantle origin. However, the lack of samples representing primitive liquid compositions and paucity of early cumulates limits the understanding of the processes that produced them.

Some of the most deeply eroded massif anorthosite complexes are exposed within the southern Eastern Ghat Belt of Peninsular India, and provide an excellent opportunity to study the processes that operated in the deep magma chambers beneath the massifs. In this area Si-undersaturated nepheline syenites are associated with anorthosite complexes, a case that is not reported elsewhere in the world. The objectives of the present study are two fold: 1) to identify the processes that acted at the lowest level of the anorthosite complexes and 2) to determine the relationship between cospatial anorthosites and nepheline syenites.

Cospatial alkaline-tholeiitic magmatism is strikingly displayed in the Chimakurti-Uppalapadu plutons within Prakasam Province. The Chimakurti pluton is concentrically zoned, and from core to margin consists of 1) olivine clinopyroxenite, 2) anorthosite, 3) olivine gabbronorite and 4) gabbronorite. It emplaced at mid-crustal depths (6 kb; 16-18 km) and is undeformed and unmetamorphosed. Comparably deep-seated massifs are strongly metamorphosed (Adirondacks) and unmetamorphosed ones typically have shallow emplacement histories (Laramie). Unlike many massif anorthosite complexes, the Chimakurti pluton is associated with a gravity high of the order of 20 to 30 mGal; consistent with the presence of ultramafic cumulates. The Uppalapadu pluton is composed of nepheline syenite (NS). An arcuate band of hornblende syenite with pockets of quartz syenite and ferro-syenite (HQF series) is present between the two plutons.

Field, petrographic, mineralogical and geochemical evidence suggests that the Clinopyroxenite-Anorthosite-Gabbro (CAG) suite of Chimakurti is formed by crystal-liquid fractionation (compounded by plagioclase buoyancy and re-melting) of tholeiitic magma. The calculated parental liquid REE concentrations to the CAG suite show LREE-enriched patterns with positive Eu anomalies, similar to the proposed parental liquids to other massif anorthosites. The HQF series represents residual liquids to the parental magma that produced CAG suite, but with crustal inputs. Attempts to model the derivation of Si-oversaturated HQF series from Si-undersaturated NS and vice-versa were not successful. The NS could be the end product of a long liquid-line-of-descent of mantle-derived alkali basaltic magma or a partial melt of shallow melting of metasomatised mantle or alkali basalt. The second possibility is favored because of the predominance of felsic rocks and almost complete absence of mafic rocks in the Uppalapadu pluton.

This study strongly suggests that 1) the ultimate source for massif anorthosites is tholeiitic mantle and the early stage of differentiation is dominated by Al-rich clinopyroxene fractionation, 2) the cospatial anorthosites and nepheline syenites are not cogenetic, but the nepheline syenites require an alkalic source. This magmatic association in the Prakasam Province is akin to the coeval alkalic and tholeiitic basalt magmatism of many rift-related environments.

V32F MC: 305 Wednesday 1330h

Volcanic Observations From Space: New Results From the EOS Satellite Instruments I *(joint with G, P)*

Presiding: **M Ramsey,** University of Pittsburgh**; L Flynn,** University of Hawaii at Manoa

V32F-01 1330h INVITED

Hekla's February 26, 2000 Eruption as seen and Measured from Space using MODIS, TOMS and AVHRR.

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The 26 February eruption started at 1819 UT. Like other Hekla events, it had a brief explosive phase which reached a seismic intensity peak after about one hour, producing a volcanic cloud that reached 11 km high. The explosive eruption then declined in intensity and a lava eruption continued from fissure vents for several days (Smithsonian GVN Bulletin). AVHRR (1945, 2125 UT) and MODIS (2100 UT) thermal IR data depict a cold (-70 C) plume with strong signal of ice during the explosive phase. The earliest (1945 UT) image has a core region with a weak volcanic ash signal and high optical depth (>2) and represents the only signal of ash found in 18 AVHRR and 6 MODIS images studied over the next 36 hours as the ice-rich volcanic cloud was tracked to the N and NNE of Iceland. The ice masses in the drifting cloud, retrieved from IR data, peak at about 100 kT 10 hours after eruption and then decline to less than 20 kT after 35 hours. SO2 masses estimated in the cloud about 17 hours after eruption were about 100 kT, while the total volume of tephra and lava erupted for the entire eruption was about 0.11 km3. We also can measure the SO2 signal with MODIS, where the ice signal complicates our results. MODIS IR retrievals yield a peak SO2 burden of 18 g m2. Multispectral MODIS IR data can be used to estimate the sulfate mass in the Hekla cloud at 1-4 kT throughout the 36 hour period. TOMS AI data also do not show an ash signal [Krotkov et al, 2000, EOS Transactions 81 (48) F1277]. We interpret the Hekla cloud to be ash-poor and gas (H2O and SO2) rich, perhaps the result of an early gas-rich explosion as carefully described by S Thorarinsson (1967, Visindafelag Islendinga, Reykjavik) for the 1947 eruption, observed from the ground during excellent visibility. Overall our results portray the stratospheric injection of an ash-poor volcanic cloud, generated in the very early stages of a small volume basaltic andesite eruption. The results compare well with previous Hekla eruptions, but the satellite detectors provide a new tool to measure from above. An unintentional aircraft encounter with an atmospheric research aircraft [Miller et al, 2000, EOS Transactions 81 (48) F1277] provided data to potentially validate SO2 and particles. The damage inflicted on the plane is consistent with volcanic ash as is aerosol particle detector data which includes significant "non volatile" aerosol. Thus there is apparently ash that was undetected by both the IR and UV detectors.

V32F-02 1350h

Analysis of Airborne Ash and Elevated Surface Temperatures Detected on Multiple Satellite Data Sets of the Mt Cleveland Eruption, 2001

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Mt. Cleveland volcano erupted in February and March 2001 producing elevated surface temperatures and ash plumes that were detected on multiple satellite data sets. A large explosive eruption that occurred on 19 February sent an ash cloud to an altitude of 9 km and was observed on Geostationary Observation Environmental Satellite (GOES), NOAA Advanced Very High Resolution Radiometer (AVHRR) and the new Moderate Resolution Imaging Spectrometer (MODIS) data. This ash cloud formed a narrow ribbon that was 1000 km long and drifted to the NE across Alaska over the next three days, disrupting air traffic throughout the region. An analysis of GOES data shows the growth and evolution of the ash cloud, and its segmentation into three parts, two of which were pulled into a barometric low and lost to view in the southern Gulf of Alaska and the third drifted north over the Arctic Ocean. Samples of the ash were collected from Nikloski, 70 km away. The ash was fine grained (mostly less than 63 micron in size) and composed of 90% glass (pers. comm. J. Gardner). Puff, a volcanic ash dispersal model, accurately predicted the movement of the complex eruption cloud on 19 February, and clouds from the 11 and 19 March eruptions. However, high-resolution, forecast wind-fields on 19 March resulted in Puff simulations that did not agree with satellite observations. Landsat 7 data recorded the 11 March eruption provided detailed observations of the plume and hot debris and ash on the southern and western slopes, which were the source of the elevated surface temperatures observed on the AVHRR data on that date. Post-eruption analyses of AVHRR data showed a possible thermal anomaly at Mt. Cleveland 3 weeks prior to the 19 February event. This eruption demonstrated that GOES can be used to track airborne ash in spite of the large pixel size (greater than 25 km2) at high latitudes. The area traversed by the February eruption cloud, as seen on satellite data, was one of the largest in the north Pacific region. The large area was due to the meteorological conditions at the time of the eruption.

V32F-03 1405h

Satellite Remote Sensing of Volcanic Clouds Using the Moderate Resolution Imaging Spectroradiometer (MODIS).

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The Moderate Resolution Imaging Spectroradiometer (MODIS) has acquired images of several eruption clouds since its launch in December 1999. We are now in a position to retrieve information about SO_2, $SO_4{}^{2-}$, ice and ash, using the constituents different transmissive properties in the thermal infrared. We are able to compare our SO_2 retrievals with the Total Ozone Mapping Spectrometer (TOMS) and our ice and ash retrievals with Advanced Very High Resolution Radiometer (AVHRR) and Geostationary Satellite (GOES) data.

We have mapped SO_2 using MODIS from both the 19 Feb. 2001 eruption of Cleveland volcano, Alaska, and the 26 Feb. 2000 eruption of Hekla, Iceland and are able to compare the maps directly with TOMS data. The scale of the Hekla eruption is more conducive to comparison with the larger footprint of TOMS, and preliminary results suggest good spatial and SO_2 burden agreement.