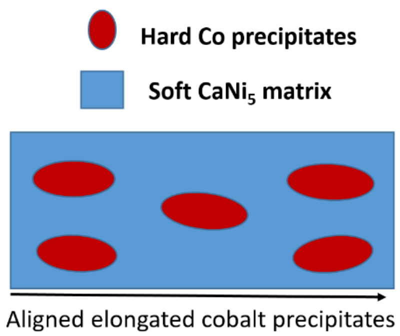
My Summer in Switzerland

Before travelling to Zurich, I had visited Switzerland only twice: on a school trip to CERN and a journey through the Gotthard tunnel to Italy. From these brief encounters I had pieced together a vague picture of the country: Switzerland was a picturesque polyglot land with soaring mountains, glistening lakes, punctual public transport and, of course, mouth-watering chocolate. My flight to Zurich only strengthened my preconceptions. Entering Swiss airspace, the stewardess handed me a delicately wrapped bar of milk chocolate, which I quickly polished off looking over the alpine foothills. Half an hour before landing, I saw the city in which I would stay for the next 8 weeks, lying in glorious sunshine flanked by the distant silhouettes of the Glarus Alps. I landed with nervous excitement, anticipating the adventure to come.

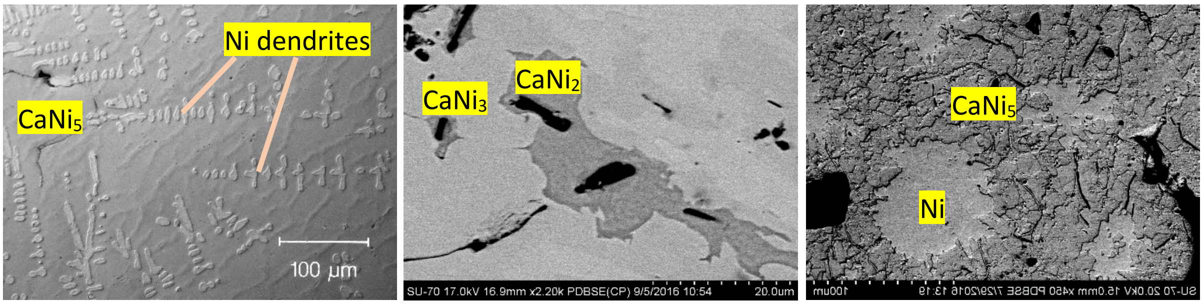
The purpose of my trip was to undertake a summer research project at the federal technical university, ETH Zurich, developing new alloys for use in permanent magnets. Permanent magnets are materials able to maintain magnetisation without an external magnetic field, and are essential in key engineering disciplines such as power generation, motors, data storage and medical devices. There are currently many classes of high-performance permanent magnetic materials, such neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sm-Co) which fulfil the technological requirements well. However they contain one key component which presents a problem: heavy rare-earth elements (HREs). HREs, such as neodymium and samarium, are used due to their high magnetic moments, giving the strong magnetisation prized in permanent magnets, but their supply is limited due to their scarcity and difficulty of extraction from ores and consequently are very costly. Therefore new alloys are needed.

There are two main approaches to solving this problem. Firstly, HREs in existing magnetic materials can be substituted for more sustainable elements. An example of this is substituting Sm in Sm-Co magnets for cerium (Ce). Cerium, a lighter rare-earth element, is more abundant than samarium and also forms the same compounds with cerium, meaning substitution without changing the intrinsic structure is possible. The cost of this, however, would be an anticipated slight degradation of magnetic properties. My work gave two key results. As expected, the saturation magnetisation, the strongest magnetic field that the magnet can provide, did decrease slightly with Ce-substitution in both common classes of Sm-Co magnets ($SmCo_5$ and Sm_2Co_{17}). However, the coercivity, the ability of a magnet to keep its magnetisation under an applied opposing field, actually *increased* in both cases. This result was completely unexpected and provides an excellent subject for further research in the area. Sm-Co magnets are famed for their high coercivity, so if these conclusions prove true, then permanent magnets based on Sm-Co have the potential to be cheaper, more sustainable and, in general, better magnets.

Secondly, alloys based on completely new systems of elements can be created and characterised. This approach helps to reduce the reliance on previous systems, providing a foundation for further research into composition and preparation to optimise the key properties. This half of my project focussed on the calcium-cobalt-nickel (Ca-Co-Ni) system, the end goal being an alloy of magnetically hard cobalt precipitates in a soft $CaNi_5$ matrix (see schematic); in theory, this combines the best properties of hard and soft magnets. Firstly, I needed to create single phase $CaNi_5$ from its constituent elements but complications arose due to the volatility and reactivity of calcium under heat. I added varying excesses of calcium and tried different techniques but I was never able to create a single phase, obtaining Ni-$CaNi_5$ dendrites, mixtures of calcium-rich phases ($CaNi_2$, $CaNi_3$, Ca_2Ni_7) and sometimes just a strange unidentifiable mix (see micrographs overleaf). Despite not reaching the end goal of single-phase $CaNi_5$, my work provided a valuable starting point to find a successful process and eventually produce the Co-$CaNi_5$ microstructure.



Desired hard-in-soft geometry of the Ca-Co-Ni system: hard Co precipitates in soft $CaNi_5$ matrix. Alloy would then be stretched to elongate the Co, optimising the magnetic properties



Selection of Micrographs from Ca-Ni study. Left: Ni dendrites in $CaNi_5$;
centre: $CaNi_2$, $CaNi_3$ and Ca_2Ni_7 three-phase mixture; right: Ni primary phase in $CaNi_5$

Aside from work, I took up a variety of pursuits while in Zurich. I played badminton and ultimate Frisbee twice and once a week respectively, went to multiple board games meet-ups, playing games I would often see at my own college's GameSoc, and even joined a choir, performing Scottish songs in a concert and helping out with the meaning and pronunciation of obscure English and Scots words (when I had a clue what they meant!). Motivated by extortionate Zurich prices and the desire for warm, cooked dinners, I developed some basic cooking skills, with the help of a cookbook from my mum.

Most weekends I went on excursions away from Zurich to explore the wider region. The highlight of the trip was travelling to Zermatt, famous for its mountain trails, ski pistes and most notably for lying under the shadow of the iconic Matterhorn. Here I walked with other keen hikers on a five-lake trail in the upper reaches of the valley before returning to the town through a thick forest and a gorge, eventually eating fondue at the town's festival to the sound of a brass band – a truly Swiss experience. To see the enormous mountain physically in front of me, not just on a Toblerone box or a computer screen, was incredible, and I endeavoured to make the most of the numerous photo opportunities. Other hiking trips involved a swimming in a rather chilly outdoor pool halfway up a mountain, a catapult made of pumpkins at a farm and sitting in rocky cable cars up and down numerous valleys. In some more aquatic adventures, I swam across Lake Zurich in the annual "Seeüberqueerung" and spent a weekend in Karlsruhe, Germany, where some friends and I savoured Weissbier and Eiskaffee on a lakeside beach near Baden-Baden after hiking in the Black Forest.

Swimming across Lake Zurich

Overall, I found my work at ETH to be a very fulfilling experience. Throughout the project, my supervisor gave me enough direction to plan my time and achieve meaningful results but also the freedom to choose and plan my experiments carefully. During my work I developed key research skills, such as documentation of procedure to allow reproducibility, thorough sample preparation to avoid failed experiments and good lab etiquette in the interests of health and safety (as well as technician sanity). Finally, I'd like to thank the Ogden Trust for providing the means to carry out a successful research project in an unfamiliar environment, see a plethora of awesome sights while exploring a beautiful country and meet some inspiring individuals in what was a truly unforgettable summer.

Hiking in Zermatt