6.0 Conclusions

The objective of this research was to characterize and compare the metallurgy and forming techniques used in the manufacture of the European and Islamic astrolabes of the Adler Planetarium. From the experimental results of the synchrotron based X-ray diffraction, X-ray fluorescence, and radiography experiments on the entire body of 40 astrolabes, along with the optical profilometry, macro and microtexture studies performed on selected astrolabe components, the following conclusions can be made.

1) The astrolabes produced in and around Lahore in current day Pakistan possessed significant evidence for the production of brass alloys by co-melting metallic Zn and Cu. This technique for brass manufacture was technologically superior to the standard cementation process of brass manufacture in use worldwide during the 17^{th} century. The Lahore metalworkers used this co-melting technique to produce $\alpha + \beta$' brass alloys specifically to exploit the alloy's hot working characteristics which allowed them to form thin (~1 mm) brass sheet without a series of working and annealing schedules required with lower Zn α brass alloys.
2) The astrolabes produced in Europe were manufactured from traditional cementation brass, limiting the Zn composition to approximately 33 wt.% and below.

3) All historically accurate astrolabe sheet formed components (retes and tympans) were formed by hand hammering brass plate to the desired thickness regardless of production location. All components that showed evidence for sheet forming by rolling were deemed to be modern replacements.
4) The synchrotron has proven to be an essential tool for non-destructive bulk analysis of the metallurgical characteristics of this collection of brass astrolabes. Without the large penetration lengths of the high energy X-rays available at the synchrotron, the bulk composition and diffraction results of this study would not have been possible non-destructively.
5) There are many astrolabe components which have illustrated a dezincification effect due to annealing during production. These components would give an unrepresentatively low Zn composition by the surface sensitive XRF technique, illustrating the essential nature of the high-energy synchrotron XRD results in fully characterizing these components. The standard non-destructive composition measurement technique in the Archaeometallurgy field today is XRF alone; for these components the XRF measurements would be misleading.
6) Optical profilometry has proven a useful tool with which to non-destructively study and quantify engraving markings on astrolabes.
7) A number of astrolabes contained components which were deemed to be modern replacements for components lost over time. These were predominantly small components such as horses and pins, but occasionally contained tympans and retes as well.

7.0 Future Work

The conclusions of this study have found that Lahore, Pakistan was a center for a fundamental shift in brass alloy production and use. While this study examined seven instruments from Lahore and one Indian astrolabe from the region, there are many more astrolabes and scientific instruments from Lahore in other collections. The findings of this study show that the metal technologies employed at Lahore were well established by 1601 AD, the date of the earliest astrolabe from Lahore in this study. It would be very useful to study earlier instruments from this region to pinpoint the exact beginning of high zinc brass alloy usage.

Another finding of this study was the broad distribution in composition for brass alloys in Iranian astrolabes of the early 18th century. Only one historically accurate astrolabe in this study exhibited the high Zn $\alpha + \beta$' brass alloy; however further study is required to conclude anything more than conjecture about the significance of the result. It would be significant and interesting to examine more astrolabes from this region and the others surrounding Lahore by high-energy synchrotron XRD to determine the dissemination and use of high Zn brasses in astrolabes and other brass sheet metalwork.

The optical profilometry technique touched on in this study has proven to be an invaluable tool for studying the engraving and surface characteristics of the Linton Arsenius and Lehigh tympan. Unfortunately due to astrolabe access these were the only two astrolabes that were able to be examined by this exciting technique. A systematic study of other astrolabes would be very beneficial to the literature. In

addition, if a number of astrolabes from a famous maker could be examined, it might be possible to study unsigned by attributed astrolabes by that maker to determine a correct provenance.

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9.0 Vita

Brian Dale Newbury was born to Dale and Barbara Newbury in Silver Spring Maryland on July 23rd, 1976. He graduated from Quince Orchard High School in June of 1994 and decided to study engineering after having won a Semi-Finalist placing in the Westinghouse Science Talent Search. Brian attended Lehigh University from 1994 until June of 1998, graduating with honors and a B.S. in Materials Science and Engineering. Having decided that the mountain and road cycling in Eastern PA were too good to leave, he decided to stay at Lehigh for graduate school. He obtained a M.S. in Materials Science and Engineering in January 2001 working for John DuPont studying nickel-based alloy weld solidification. He has been studying medieval European and Islamic metallurgy ever since, conjuring up ancient brass alloys from medieval texts from time to time while obtaining his doctorate. Upon graduation he plans on spending more time with his first love, fiancée Melissa Lim, and reacquainting himself with that which got him interested in metallurgy in the first place, his numerous bicycles.